THE

GEOLOGICAL MAGAZINE

NEW SERIES. DECADE VI. VOL. II.

No. VII.—JULY, 1915.

ORIGINAL ARTICLES.

I.—The Geological Age of the Carrara Marbles.

By Professor T. G. Bonney, Sc.D., F.R.S., and the Rev. H. H. Winwood, M.A., F.G.S.

THE statuary marbles of Carrara have been repeatedly asserted to be metamorphic limestones of earlier Mesozoic or later Palæozoic age. Similar statements were once frequent in regard to other mountain regions, but they have one by one dropped out of geological literature. This, however, is such a hardy perennial as to be still repeated in petrological and other textbooks.[1] Doubts, however, were felt by the first author in 1878, and these became almost certainties after 1886, but as each visit was only for a few hours,[2] and did not allow of a proper examination of the rocks in situ, he deferred writing on the subject till he could spend a longer time at Carrara. That opportunity, however, never came, and is not now likely to occur; but on finding not long since that his friends, Professor Boyd Dawkins and the Rev. H. H. Winwood, had visited the quarries in 1898, and the latter had published an account of the district, with a sketch-section drawn by the former,[3] he communicated with them, and the following paper summarizes the experience of the three, which it is hoped may help in laying another metamorphic ghost.[4]

[1] See, for example, *Text-book of Petrology*, vol. ii, Sedimentary, F. H. Hatch and R. H. Rastall, 1913, p. 250. In books of earlier date the marbles are said to be Lower Jurassic, *Building and Ornamental Stones*, E. Hull, 1872, p. 127; Triassic, *Traité de Géologie*, A. de Lapparent, 1906, p. 1100; Upper Triassic on the *Carta Geologica della Liguria*, by A. Issel and S. Squinabol (1891), and they are associated with micaceous schists in a short text published with the map. They are assigned to the same age in a description of an excursion to Carrara, *Bollettino della società Geologica Italiana*, vol. xxi, p. 163, 1902, which classes some underlying schists and marbles as Permo-Carboniferous, and some schists beneath those as indeterminate Palæozoic, and gives the following succession of the overlying beds, from the base of the Miocene sandstones and conglomerates: Eocene, sandy and calcareous strata; Upper Cretaceous, varied deposits; Lower Cretaceous, limestones; Tithonian, Lias and Rhætic, various; all these being more or less fossiliferous. W. P. Jervis, however, *I Tresori sotteranei dell'Italia*, vol. iv, p. 261, 1889, regards the marbles as pre-Palæozoic. A summary of Italian opinion prior to 1878 is given in this Magazine by Professor G. A. Lebour (1878, pp. 289 and 382). He adopts Coquand's verdict for a Carboniferous age.

[2] Unfavourable weather made both shorter than had been intended.

[3] Proceedings of the Cotteswold Naturalists' Field Club, vol. xiii, p. 57.

[4] For the paragraph marked thus § Mr. Winwood is mainly responsible; for those marked thus ¶ Professor Bonney.

§ The Carrara Mountains, also called the Apuan Alps, are a short range of bold peaks rising abruptly from the Apennines to a height of some 6,000 feet above sea-level, in striking contrast with the tamer scenery of the coastal zone. Their steeper slopes are deeply gashed by valleys and carved into spurs, on one of which, between the Maira and the Serchio, lie the noted quarries of Carrara and Massa. These, with others in the district, are high up on the mountain side; the slopes of white debris at a distance resembling snow, and increasing the likeness to an outlier of the Alps. Mr. Winwood, with Professor Boyd Dawkins, began by visiting quarries, of which one furnishes the ordinary clear white Carrara marble, called *Marmo Siciliano*,[1] used in architecture and for common statuary, and the other a kind still better adapted for the latter purpose, which also has been employed in Trajan's Column and the Pantheon at Rome.[2] From these they passed on to quarries in the Piastra Valley, which supply the *Marmo Statuario*, the use of which is signified by the name, and then to others (at a lower level) which yield the *Marmo Bardiglio*, bluish in colour, and sometimes varied by dark veins. On the following day they went to quarries in glens leading down to the Bedizzano Valley, of which some had been worked by the Romans. These also furnish good white marble; the highest point reached, a quarry at La Gioija, being at an altitude of about 1,900 feet. In descending to the Colonata Valley, they obtained a good continuous section of the rocks (in ascending order) which is represented in the annexed diagram, copied from a rough sketch by Professor Boyd Dawkins, the basal line running from about 624 feet to 1,400 feet above the sea.

Fig. 1.—Diagram of Strata in Colonata Valley.

1. Conglomerate (Recent). 2. Crushed Sericite Schist. 3. Micaceous Schist (Bedizzano Valley). 4. Veined Sicilian Marble (910 feet). 5. Pavonazzo Marble. 6. Bardiglio Marble (Torone 1,241 feet). 7. Sicilian Marble. 8. Schist (Colonata Valley).

On this section Mr. Winwood remarks that the beds apparently dip at a high angle (in some instances they are nearly vertical), but that it was sometimes difficult to ascertain whether this was true dip or cleavage. In one quarry (Ravaccione) the signs of crushing are very marked; these could be seen in other places, as well as signs of faulting, but the intercalation of the marble in the schists appeared to be indubitable.

[1] So called, I have been informed, because at one time it was conveyed to Sicily and exported thence to other places.—T. G. B.

[2] There are other quarries of different varieties of marble, one important group being near Seravezza, to the south-east of Carrara and Massa. See *Vasari on Technique*, edited by G. B. Brown, 1907, pp. 45–8 and 119–26.

¶ On Professor Bonney's first visit he did little more than examine the quarried rocks and fragments, more or less water-worn, brought down by the stream which debouches near the town of Carrara. On his second visit he walked for some distance up the valley, collecting specimens of the micaceous schists, often gneissic in aspect, which were fairly common. All of these showed signs of crushing while in a crystalline condition, and some a conspicuous cleavage-foliation. He failed, however, to find any specimens of a marble with lines of mica and chlorite (?) which he had seen built into the walls of the Croce di Malta Hotel at Spezzia, or any marked signs of mechanical disturbance in the pebbles of ordinary marble, most of which were pure white, but some showed a lead-coloured clouding or streaking. He then ascended to Miseglia, on the right bank of the valley, without finding any good sections *en route*, owing to overgrowth, but ascertained, especially in a quarry near this village, that an ordinary dark limestone, with indications of mechanical disturbance (resembling some near Spezzia and others of Jurassic age in the Oberland Alps), which was associated with lighter-coloured varieties, occurred in close proximity to normal Carrara marble.

¶ On this occasion he collected a few representative specimens of the gneissose and schistose rocks, and one of the former had been given to him, about 1885, by the late Professor Carvill Lewis.[1] This specimen, labelled by the donor "sericite-schist, Upper Triassic, Carrara", has a gneissose aspect, and is obviously much crushed, the curving cleavage surfaces glimmering as usual with a minute silvery mica.[2] A transverse section exhibits zigzagging bands of two principal constituents, the less abundant almost black, the other nearly white. The latter, though sometimes rather like felspar, proves on examination to be really quartz. The microscope shows that this mineral forms rather polygonal grains, varying in size from about one-fiftieth of an inch down to mere specks. The larger grains often occur in small groups which are suggestive of broken-up veins. The quartz is associated with an almost colourless mica. A few of the flakes are about ·01 in. long, having a faint brownish tinge, and giving bright colours with crossing nicols, but the majority vary on either side of ·002 in. in length. These, I suspect, are produced by the shearing of larger flakes. The dark mineral mentioned above often occurs in more or less clustered granules, which so far as they have a definite shape are slightly prismatic. They show a metallic lustre with

[1] I think he gave it to me shortly before my visit in the autumn of 1886, remarking at the time: "Here is a gneiss of Triassic age from near Carrara." My reply was to this effect: "If you had told me you got the specimen not far from the St. Gotthard, on the northern side of the Val Bedretto, I should not have been surprised. Was there in the field an actual sequence from it to indubitable Triassic rock?" "Not exactly," he answered, "but they were exposed on opposite sides of a valley." "Well, then," said I, "a fault may have gone down that valley, so, though greatly obliged to you for the specimen, I cannot admit that it has been proved to belong to the Triassic system."—T. G. B.

[2] See Presidential Address to the Geological Society, Quart. Journ., vol. xlii, Proc., p. 65, 1886. See also id., vol. xlvi, pp. 202-4, 1890, and other papers of mine on Alpine schists.—T. G. B.

reflected light, their colour being more of a very dark brown than black, but they give a black streak, with a faint undertint of blood-red, so I expect they are really magnetite with slightly oxidized surfaces. Kyanite, if I rightly identify it, is present in rather elongated prisms, also a few minute prisms of a slightly bluish-green mineral, with a high refractive index and a straight extinction, which is almost certainly tourmaline, and a small, rather acicular, brownish mineral, not unlike rutile.[1] Thus the rock is a quartz-mica schist rather than a gneiss, and has evidently undergone some shearing, though the quartzes do not show strain shadows.

¶ Of five specimens (collected as generally representative) from the stream bed above Carrara and below Miseglia, one has the aspect of a much crushed gneiss, with a rude but distinct cleavage. In colour it is whitish, with lead-coloured spots, and on its external flattened surfaces are 'smears' of a similar coloured mica. Microscopic examination shows the rock to consist of quartz, in grains often slightly elongated, from about ·02 in. to ·001 in. in diameter; the larger often having ragged edges. Flakes of an almost colourless mica, giving bright polarization tints, occur between the grains, especially the larger, their length being from about ·006 in. downwards. Granules of an iron oxide, similar to that in the last specimen, occur singly and in 'coveys' with three or four rounded or quadrangular grains of tourmaline, varying in colour from brownish to blue; also one or two of apatite, and the above-mentioned brownish microliths. A second specimen, which it seemed needless to slice, is on the whole intermediate between the two now described, but the crush surfaces are more irregular than in the former, and the rock is more 'mottled' in texture, being traversed by patches of the lead-coloured mica, which has a very silvery lustre.

A third specimen, evidently crushed, for it exhibits a very rude cleavage, is rather white in colour, and resembles a fine-grained, quartzose gneiss, with a fair amount of silvery mica. But microscopic examination does not reveal any felspar, though the former presence of that mineral may possibly be suggested by a clear grain, containing here and there numerous minute specks suggestive of an aluminous residue, and seemingly having a slightly higher refractive index than an adjacent grain indubitably quartz. The mica resembles that already described, exhibiting a distinct foliation, but not very obvious signs of crushing.

¶ The specimens described above present a general resemblance, especially under the microscope[2] to the quartz-schists, which not infrequently occur in the Alps. My collection contains specimens obtained at intervals from the south side of the Great St. Bernard to the west one of the Gross Glockner. They are well developed in the Einfischthal, especially near Vissoie and around Zinal, where they not unfrequently contain pebbles, and about Saas Fee, where they

[1] Mr. R. H. Rastall, who has had considerable experience in examining microlithic minerals, informs me that the colouring matter appears to him mainly external and suggests brookite as a possible identification.

[2] It shows the gneissose aspect to be illusory, the apparent felspar granules being due to pulverization of the quartz.

sometimes include bands of mica from fully one-third of an inch in thickness down to mere streaks. They also occur on the south side of the Gorner Grat, near Pianura di Segno on the Lukmanier Road, to the south of Splügen village, and in the upper part of the Averserthal, associated with dark mica schists and calc-mica schists which pass into white marbles. So far as I have seen, these quartz schists generally occur low down in this group of the Upper Schists.[1] They also have some resemblance to a quartz schist from a hill north of the west end of Derrylea Lough, Connemara,[2] to one from Morone in the Braemar district (though this rock shows less signs of crushing), and still more to another one nearer that health resort. These quartz schists present some resemblance to the highly crushed basal Cambrian quartzite of Glendhu (Sutherland), in which, however, any argillaceous constituent is less altered, and to crushed Torridonian near Kinlochewe and Loch Clair, in which also mica is not so well developed, fragmental felspar still remaining.

¶ A fourth specimen from the same valley is a schist with much mica, slightly brown or greenish in tint, and quartz; both small, the latter slightly the more abundant, and the former showing sharp waves or loops, with roughly parallel axes, as if a little more flexure would have produced a strain-slip cleavage. Under a quarter-inch objective, the quartzes are seen to be slightly elongated and the mica almost colourless, but interspersed with it are rather numerous pale umber-brown granules, slightly prismatic in form (? minute staurolites) and a few which are opaque, probably an iron oxide. Three or four prismatic grains, greenish-blue in colour and pleochroic, are probably tourmaline. A fifth and smaller specimen so much resembles this one that it has not been sliced. I have obtained rocks similar to these from more than one part of the Alps where pressure has produced conspicuous effects; occasionally from that 'waiting room' named Casanna Schiefer, but more often from the Upper Schists. For instance, they much resemble a specimen obtained between Mittersill and Kitzbühel on the southern side of the pass near the top.

¶ I have examined only a few slices of Carrara marble, because I could not collect my specimens in situ. Those of the best marble are granular in structure, consisting of crystalline calcite with a variable amount of dolomite, showing some pressure twinning but no signs of crushing; one of them containing two or three tiny fairly idiomorphic quartz crystals. A specimen labelled "brecciated marble, Seravassa"[3] is a crystalline dolomite.[4] It consists of pieces or bands of coarser texture in a finer-grained matrix. The Carrara marble is very similar to that from Pentelicus,[5] which, however,

[1] Quart. Journ. Geol. Soc., vol. xlv, p. 95, 1889.

[2] Perhaps also to the quartz-rock of the Twelve Pins, which I have not actually visited.

[3] For which and other interesting specimens of marbles I have to thank Mr. W. Brindley, of Westminster.

[4] In the Binn Valley crystalline dolomites are interbedded with dark mica schists.

[5] This is asserted to be Cretaceous (Hatch and Rastall, *ut supra*, p. 250). I have seen a little of this neighbourhood and am unable to accept the identification.

affords a rather more distinct indication of pressure, as does the well-known Cipollino from Eubœa, which, of course, contains more pale-green mica, etc. It is also nearly identical with the white marbles here and there intercalated in the above-named dark mica schists, the isolated masses of marble on both sides of the Tosa about Ornavasso, and those seemingly intercalated in gneiss on the Splügen Pass, and on the descent from the San Bernardino Pass to the baths of the same name.[1] But all of these afford distinct indications of some amount of crushing. They differ much from the dolomites of the South-Eastern Tyrol and from some rather marble-like limestones in other parts of the Alps, both of Mesozoic age; even from the remarkable imitation, but imitation only, of Cipollino marble worked near Saillon in the Rhone valley not far from Saxon.

¶ The absence of signs of crushing in the best Carrara marble, while it is so marked in the schists, is certainly a difficulty, but we must suppose, and I have little doubt that a fuller study of the sections in the field would show it to be the case, that the statuary marble is obtained from lenticular masses which have been saved from being crushed by the yielding of adjacent bands. I have noticed something of this kind in one or two of the Alpine marbles.

Thus the evidence obtained in the field and from a study under the microscope of the schists and marbles of Carrara is altogether adverse to the hypothesis of a Mesozoic, or even later Palæozoic, age. That, as with similar rocks in the Alps, is most probably Archæan. The region is one where the rocks have been much faulted, but in which those indubitably Mesozoic retain their usual aspect and character; as is their habit, so far as I have seen, in districts such as the Alps, where pressure-metamorphism has produced notable effects.

II.—On the Formation of the River Tyne Drainage Area.

By Edward Merrick, M.Sc.

THE object of this essay is to outline the connexion between earth-movements and the formation of the River Tyne drainage area; the period of its formation is also alluded to, though it is less definable. This object becomes more accessible on dividing the area into the following parts and considering each separately:—

A. The Main Valley of the Tyne.
B. The Watersheds South of the Main Valley.
C. The Watersheds North of the Main Valley.
D. The Earth movements considered stratigraphically.
E. The Relationship to other Drainage Areas.

A. The Main Valley of the Tyne.

The rocks forming the drainage area of the River Tyne are all Palæozoic, and except for a small inlier of Silurian deposits at the

[1] After careful examination I formed the opinion that the apparent interbedding was illusory, and that they were nipped in by thrust faults. Where, however, the marble was associated with the calc-mica schists it obviously graduated into these.

head of the Redewater they are all members of the younger Palæozoic period, the youngest member of which, the Permian, covers but a very small area on the East Coast. Up to the present no later deposits, except the Glacial and post-Glacial deposits, have been discovered in this area.

In other parts of England—the Kent Coal-field, the Bristol Coal-field, the Cotteswolds, and the Staffordshire Coal-field—the Mesozoic deposits rest unconformably upon a junction-plane of Palæozoic rocks, the Trias being frequently the first unconformable deposit upon it.

In South Durham there is no exposure of the junction of the Permian and Triassic rocks, and there is some conflict of opinion as to where the divisional line is to be drawn in some borings passing through them. Still, for practical purposes, the Tyne area may well be regarded as a continuation of this junction-plane which has been eroded into the present system of hills and valleys. Placing the formation of this junction-plane, peneplain, or surface of planation—whatever the causes were which produced it—as originating about this time, it follows that it was probably affected by the later movements proved in adjacent areas, and that such movements were liable to follow the same general trend and lines of weakness as the pre-Permian movements. Something of this kind must have taken place, for when walking westwards along the left or north bank of the River Tyne it is noticed that the surface-levels of the country to the north are typically lower than on the south or right bank, and that this difference continues to increase on walking westwards. In other words, the Durham side of the river has higher contours than the Northumberland side.

The following Table of Levels, taken from the 1 inch Ordnance Survey Maps, illustrates this difference. The most easterly stations are at the head of the list:—

TABLE I.

LAND LEVELS IN FEET.

Left Bank.	Height.	Difference.	Height.	Right Bank.
Tynemouth[1] . .	120	*157*	277	Cleadon.
Moorhouses . .	242	*65*	307	Down Hill.
Scaffold Hill . .	253	*3*	250	No hill, but rising ground.
Byker Hill[1] . .	214	*286*	500+	Beacon Lough.
Condercum . .	409	*290*	700	Tinkler Row.
Westerhope[1] . .	435	*314*	749	Near west of Sandy Gate.
Heddon Laws . .	501	*84*	585	High Spen.
,, ,, . .	,,	*404*	905	Billingside.
,, ,,[1] . .	,,	*534*	1,035	Pontop Pike.
Harlow Hill . .	554	*296*	851	West of Currock Fell.
,, ,, . .	,,	*76*	620	Near Edgwell House.
Kip Hill . . .	649	*311*	960	Kilnpit Hill.
,, ,, . . .	,,	*264*	913	No name.
,, ,,[1] . . .	,,	*582*	1,231	Stoterley Hill.
Little Whittingham .	689	*571*	1,260	Edmundbyers Common.
,, ,, .	,,	*343*	1,032	Pit House Fell.

[1] Picking out the five marked hills as least denuded.

TABLE II.

Tynemouth	157	feet lower than the hills on the right bank.
Byker Hill	286	
Westerhope	314	
Heddon Laws	534	
Kip Hill	582	

The second table clearly brings out the steady increase of difference in surface levels on walking westwards, which is quite evident, as both watersheds are near together. However, on nearing and passing Hexham, it is not so easy to make a table as above, because the chief eminences of the watersheds are widely separated. The southern watershed of the River South Tyne is very much higher than the watershed between the North and South Tyne, by about 1,000 feet; a still greater difference in levels than at Kip Hill. Between these two watersheds lies a wide synclinal hollow, the main valley of the Tyne. Bearing this difference of levels in mind, the thought arises that it may have been caused by a fault running from east to west, with its downthrow on the north, the magnitude of the downthrow also increasing from east to west.

Consider now what the effects of such faulting of the junction-plane would be besides producing this difference in levels. (See Fig. 1.)

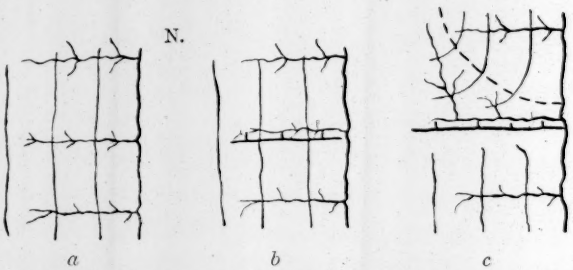

FIG. 1.—Alteration produced in the course of parallel contour-lines by faulting at right angles to them. *a*, Original state. *b*, Position of Fault [Stublick Dyke]. *c*, Position of watershed to the induced tributaries [i.e. position of the Corbridge Fold and the North Tyne].

1. Far to the north of this fault the contour-lines would still run in their original direction, parallel with the coastline of that period, but on coming southwards they would sweep round towards the west, ultimately becoming parallel with the fault. (Fig. 1*c*.)

2. The alteration in the direction of the contour-lines and slope of the country would be accompanied by a change in the river drainage on the north of the fault, for tributaries would come from the north and north-west, increasing in length where the throw of the fault was greater.

3. A watershed running in a general north-westerly direction from the fault would be produced to the north-east of these induced tributaries. (Fig. 1*c*.)

4. Faulting to such an extent as this could not take place without affecting the lie of the solid rocks.

5. It would result in bringing younger rocks against increasingly older ones on passing from east to west. (Fig. 2.)

6. The *strike* of the rocks would follow the general trend of the contour-lines as already described.

7. Where the throw of the fault was small, the alteration in direction of the lines of strike and contour-lines would also be small, and they would still resemble ancient shore-lines through being nearly concurrent with those in process of formation.

8. The course of the main river would be concurrent with that of the fault. (Fig. 1*c*.)

The next step is to examine the surface and geological features of the area to see if such disturbances and results have taken place. Taking each of the above considerations in turn, it is found that—

1. If the valleys of the Tyne area be imagined as being filled up as high as the original surface of the junction-plane, the contour-lines do then change their direction as mentioned. This reconstruction of the surface contours can be done on the 1 inch contoured map by joining the most easterly and southerly occurrences of the same contour heights together by a line bounding them from the area on which that height does not occur.

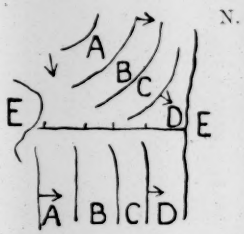

FIG. 2.—Diagram of the strike in the strata in the same area as Fig. 1c. E = Later deposits. D = Permian. C, B, A = Carboniferous.

2. The North Tyne and its tributaries are seen to flow in a direction consistent with the above reconstruction.

3. A watershed does run in this direction, which is the same as that of the Corbridge Fold originally described by Professor Lebour.

4. The lie of the rocks and the heights at which they outcrop are changed. The Corbridge Fold and the extension of the Coal-measures (with a southerly dip) along the Tyne valley are partial results of this faulting.

5. The Ninety Fathom Dyke, which runs generally east and west, throws the Magnesian Limestone and Yellow Sands of the Permian against the Coal-measures, and younger Coal-measures against older Coal-measures, at its eastern exposure. Further inland the Stublick Dyke commences, which brings the Coal-measures successively against the Millstone Grit, Carboniferous Limestones, and Shales on proceeding westwards. At the extreme west this junction-plane has been lowered to such an extent that Triassic rocks were deposited upon it. It must be pointed out, however, that at Cullercoats the present land levels are the same on both sides of the Ninety Fathom Dyke, yet

near Tynemouth the two banks of the Tyne are at different levels, as already shown in the above table. This would seem to indicate by its influence on the Tyne banks that the Heworth 25 fathom dyke, rather than the Ninety Fathom Dyke, is to be considered as the easterly continuation of the Stublick Dyke, for it extends the difference in levels produced by that dyke. This would also indicate that the Ninety Fathom Dyke is the oldest of the three faults.

6. The general *strike* of the strata does follow that of the restored contour-lines.

7. The restored contour-lines, up to 300 feet in the eastern area, are fairly concurrent and in general trend follow that of the present-day coastline.

8. The main valley of the Tyne is concurrent with the Stublick and Heworth dykes, and is therefore very straight.

If a line be drawn on the north bank of the river from Fourstones Railway Station to the Coastguard Station at Tynemouth, then the river lies wholly to the south of it; similarly, the river lies wholly to the north of a line drawn on its south bank from Stocksfield to Heworth Shore. On drawing a line half-way between these two boundary-lines, the mean course of the existing river is obtained. From this line the windings of the river are measured in the following table, the easterly stations being at the head of the list:—

TABLE III.

Locality.	Deviation or Winding.
Tynemouth	1·8 miles north
Heworth Shore	1·9 ,, south
Team Mouth	1·775 ,, ,,
Stocksfield	2·125 ,, ,,
Fourstones Station	2·275 ,, north
Maximum winding	4·4 miles in all.

The north and south bounding-lines diverge westwards and are cut off by the Pennine Fault and Triassic deposits.

It is rather peculiar that Condercum—409 feet—lies near the mean course of the river, and that there is no land north of it which reaches this height. Byker Hill is also in a similar position. Condercum is on the south or upcast side of the Ninety Fathom Dyke, and stands upon sandstone, of which material Byker Hill is also composed. The strata dip gently from these two hills towards the present position of the river. Denudation beginning in the softer materials above this sandstone has worked southwards and cut downwards till the present river valley was formed, leaving these hills as monuments of the former height of the land. It is not necessary to conclude that these hill-tops were actually the bed of the river in times past, for the mean course of the river is drawn, not from the past, but from the present windings of the Tyne.

B. The Watersheds South of the Main Valley.

On going along the foot of the Cross Fell escarpment from north to south, the solid rocks are seen to have been faulted down to the west, while those on the east or upcast side have been bent into an anticlinal arch. Consider what the effect of this combined movement

would be *supposing* some or all of it to have taken place after the formation of this junction-plane. (Fig. 3.)

Effects of the anticline on the east of the Pennine Fault :—

1. Near the fault there would be a system of nearly parallel contours on each side of the axis; owing to the general easterly slope of the country these contours would meet by wrapping round Cross Fell as a centre, giving it the appearance of a half dome.

2. A somewhat radiating system of streams and watersheds with an easterly trend would originate from this half dome and the long axis of the anticline.

3. The synclines on each side of the long axis would be the lowest ground in the neighbourhood, and water would therefore drain into them and newer deposits would be liable to form in these areas.

4. The Stublick Dyke would now lie in the northern syncline.

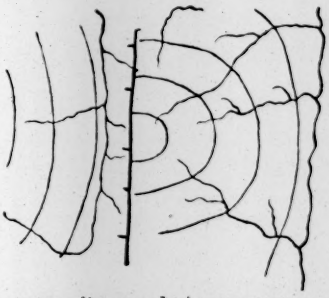

FIG. 3.—Diagram of contour-lines and river courses on both sides of a fault cutting a peneplain buckled into an anticline [i.e. the Pennine Fault and the Cross Fell Anticline].

Effects of the anticline west of the Fault :—

5. If the long axis of the Cross Fell anticline still dipped to the east, i.e. rose to the west, the contours of this junction-plane would partially encircle the mountains of the Lake District; those contours near the escarpment foot would, however, be straighter than those on the top.

6. There would be a tendency for a river or a watershed to form above the long axis of the anticline (at right angles to the Pennine Fault), depending upon whether the slope of the long axis was steeper or not than the slope of the limbs of the anticline.

Effects of the Pennine Fault :—

7. The land surface being lowered on the west would produce a repetition of the contour-lines occurring on the east of the fault.

8. The throw of the fault would be measured by the displacement of the contours. (Fig. 4.)

9. A north and south watershed would be produced along the top of the escarpment face.

10. A fairly straight stream flowing generally parallel with the fault would form at the foot of the escarpment.

11. This stream would be fed by streams from the fault escarpment and collect tributaries from the west and south-west.

12. The area near the fault would be liable to be covered by younger deposits.

Taking each of the above considerations in turn and examining the surface and geological features of the area, it is found that—

1. The contour-lines of the restored surface run in an elliptical shape round Cross Fell as a centre.

2. The South Tyne, Wear, and Tees radiate from Cross Fell, while the long axis of the anticline acts as the watershed between the Tyne and tributaries to the Wear and Tees.

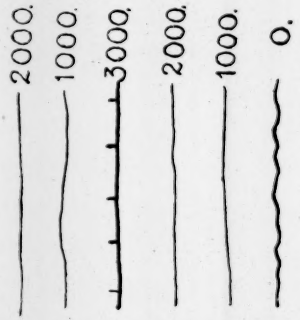

FIG. 4.—Land levels repeated by faulting parallel with the contours [i.e. Pennine Fault and escarpment face].

3. The main valley of the Tyne lies in the northern syncline, and that of the Tees in the southern, in which Triassic rocks are present.

4. The Stublick Dyke is in this position.

5. The contour-lines do run in this general direction near the mountains, but they are covered over near the Pennine Fault.

6. The River Eamont, which flows through Lake Ullswater and onwards till it joins the River Eden near Culgaith, occupies the position of this inferred anticlinal axis.

7. The contours are repeated, but those near the Fault are out of reach.

8. Regarding the Fault in this light, and subtracting the thickness of the Mesozoic rocks from the present-day land levels, then subtracting this level from the height of Cross Fell, an approximate value for the throw of the Pennine Fault during post-Palæozoic times is obtained.

9. There is a watershed in this direction.

10. The River Eden occupies this position.

11. Tributaries are received from these directions.

12. The Trias is present in this area. (Fig. 5.)

The general direction and slope of the southern watershed are from Cross Fell (2,930 feet), to Cleadon (277 feet), which is 48 miles away.

If this watershed were a peneplain, then, by drawing a sloping line between these two heights, the levels that the hills in between should reach can be marked off along it. When this is done it is found that the actual heights of the hills are below their calculated ones, and that on leaving Cross Fell the difference increases, then

decreases on nearing Cleadon; the greatest difference being half-way between the two places, where instead of the land level being at 1,500 feet, it is 1,000 feet, thus indicating that a slight bending, a sagging of 500 feet, has taken place. (Fig. 6.) The tendency of this bending is to space the contour-lines nearer together in the west and further apart in the east, till near Cleadon, when they come

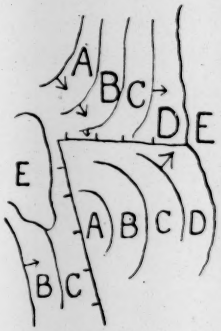

FIG. 5.—Diagram of the strike of the strata in the same areas as in Figs. 2 and 3. E, D, Later deposits. C, B, A, Carboniferous.

closer together. The tributaries from this watershed are naturally influenced by this bending. The change in position of the contours influences the direction in which the streams flow.

The Rivers South Tyne, West and East Allen, and the Devil's Water all run nearly at right angles from the watershed, but owing to the bending the River Derwent runs along a slanting course into

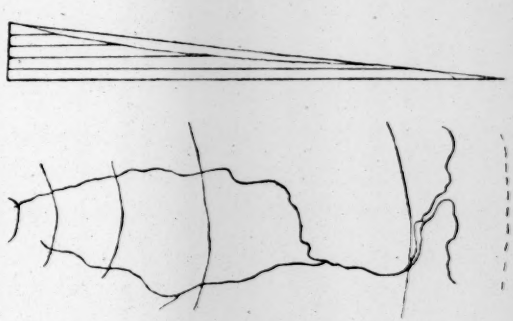

FIG. 6.—Slight sagging of a peneplain causing different spacing of contours [compare with the Wear drainage area].

the Tyne Valley. The lessening of the slope by the wider spacing of the contours gives the streams greater liberty for forming a meandering course. Had this bending increased beyond a certain amount, a ridge or dome would have been formed near the coast, and the contours would have wound round it instead of around Cross Fell;

this would also have caused the meandering streams on the flat area to turn either to the south or north, so as to pass round it to the sea. (Fig. 7.)

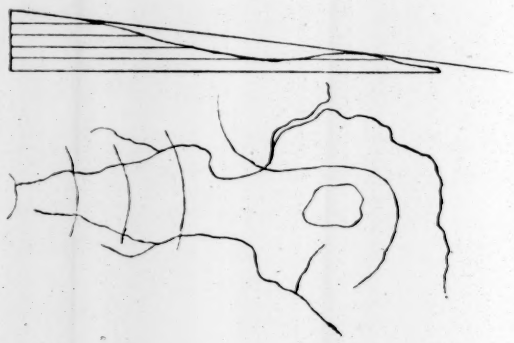

FIG. 7.—Decided sagging of a peneplain causing a coastal dome or range of hills [compare with the Tees drainage area].

Are the changes in direction of the Rivers Tees and Swale produced by such bending, and did the Cleveland Hills originate this way?

C. The Watersheds North of the Main Valley.

The watersheds on this side of the River Tyne may be considered as forming four districts—

1. That from the coast to near Corbridge has a watershed nearly parallel with the Tyne and is an example of the drainage of a gently sloping plane.

This district gives no important tributaries to the river. The largest one is the Ouseburn, whose chief collecting-ground is to the north of the Ninety Fathom Dyke, which drains this area towards itself, the Ouseburn cutting across the line of fault in the region of its greatest amount of throw.

2. The alteration in direction of the watershed from Corbridge towards Bellingham has already been described in the section on the Main Valley of the Tyne.

3. The Rivers North Tyne and Reed form another district consisting chiefly of a main watershed on the Cheviots, running from Blackhall Hill to Caplestone Fell, from which a parallel system of streams and watersheds runs at right angles. A confluence of the streams takes place before the united river crosses the outcrop of the Great Whin Sill. This great mass of whin causes escarpment lakes on the north of the Tyne through cropping out along a plane which is not very much eroded, but south of the Tyne it causes waterfalls through cropping out by deep erosion of overlying rocks. The exposure on the Cross Fell escarpment is also notched by waterfalls.

4. The remaining district is that connecting the watersheds on the west of the North and South Tyne Rivers.

Hitherto the influences of the Pennine and Tindale (Stublick) Faults upon the junction-plane have been taken as guides to the

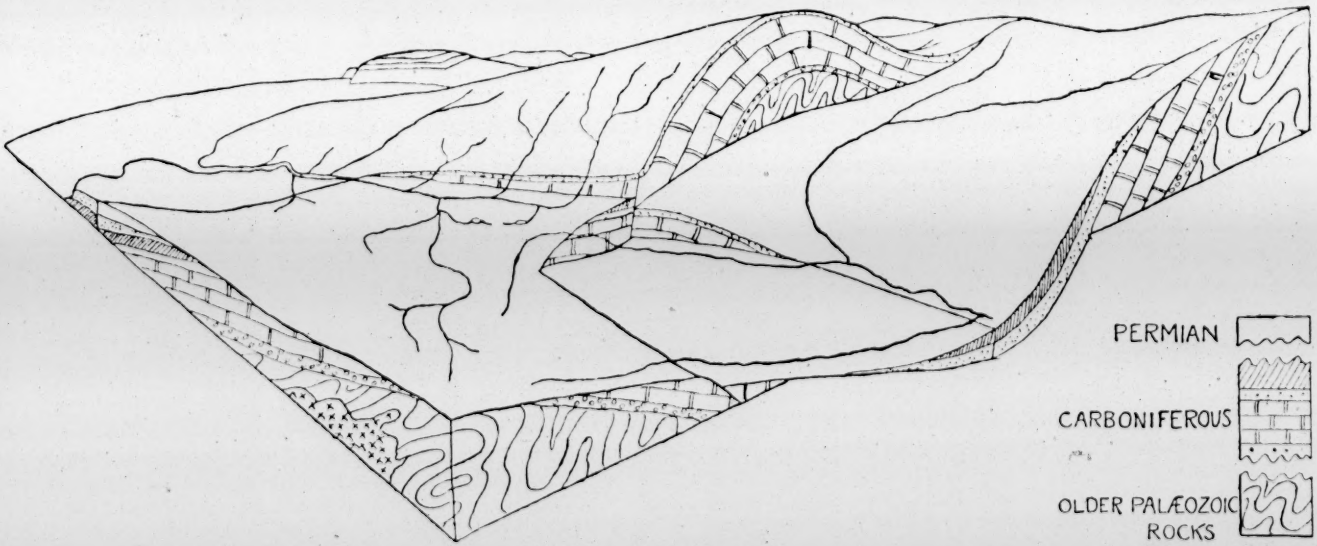

FIG. 8.—A bird's-eye view, looking south-eastwards from the Cheviots, of the Tyne area on the left and the Eden area on the right. Cross Fell is near the centre, and the Yorkshire coast (Mesozoic) is over the south-eastern watershed of the Tyne. The sections are from the Cheviots to Cullercoats on the left and Cheviots to the Lake District on the right, omitting the Permian and Trias. The bottom edges of the diagram are at sea-level. (Not drawn strictly to scale.)

river drainage. It is perhaps as well to continue on this line of inquiry. As is well known, the Pennine Fault throws down in a westerly direction and the Tindale Fault throws to the north. Should these two Faults intersect, there would be four fault faces at this intersection, and supposing the Mesozoic and Glacial deposits were removed we should see the south-east solid angle standing higher than the three others, while the north-western one would be the lowest of all through being thrown down by both faults. The depth at which the Palæozoic rock surface lies is not known, yet it is probably not so great as where it troughs under the Cumberland Plain and under the Solway.

Whatever the position of this old surface may have been in the past, we know that it is now buried under Mesozoic deposits. As these deposits were formed upon it, they would follow its general contours, their degree of dip having a tendency to lessen as they increase in thickness. When later movements set in, these deposits would still retain their parallelism with this buried surface. As a result of this, the present-day drainage system should be similar to that which would be formed upon this surface were the younger rocks removed and the land raised so as to be above sea-level. (Fig. 8.) The contour-lines of this surface would sweep round to the north-west on leaving the Tyne area and run towards the Cheviots. This change in direction on leaving the main valley of the Tyne would produce a watershed running in a northerly direction between the tributaries to the North Tyne and to the Eden from the north-east. As a result of this watershed and the westerly slope of the trough towards the Solway, no rivers would flow out of the Eden area into the Tyne area across the Pennine fault.

The configuration of the present drainage area of the Eden agrees very well with the construction above given, and therefore supports the mode of origin of this part of the Tyne watershed, the irregularities of which, as also in the other parts, are caused by later denudation producing sinuosities in its direction across country.

(To be concluded in our next number.)

III.—The Bekinkinite of Barshaw (Renfrewshire), and the Associated Rocks.[1]

By G. W. Tyrrell, A.R.C.Sc., F.G.S., Lecturer in Mineralogy and Petrology, University of Glasgow.

Introduction.

THE recognition of teschenites in the Midland Valley of Scotland, first by Teall [2] and later by several other petrographers, has led to the discovery of numerous varieties of analcite-rich rocks in the same area.[3] One of the most interesting of these is the unique rock discovered in an old quarry at Barshaw near Paisley, during the remapping of the district by the officers of the Geological Survey of

[1] This paper forms part of the results of a research which has been aided by a grant from the Government Grant Committee of the Royal Society.

[2] *British Petrography*, 1888, p. 359.

[3] Tyrrell, Geol. Mag., Dec. V, Vol. IX, pp. 69–80, 120–31, 1912.

Scotland. A preliminary description of this rock as a weathered theralite was given by Mr. E. B. Bailey in 1909.[1] In the previous year a chemical analysis by Mr. E. G. Radley had appeared.[2] A fuller description is given in the Survey Memoir on the Glasgow District (1911).[3] According to Mr. R. G. Carruthers the theralite is probably part of an igneous mass which is persistently found at the Hurlet Limestone horizon of the Carboniferous Limestone Series in the Paisley district. The petrography of the rock, as investigated by Mr. Bailey, makes clear its relationship to the melanocratic ijolites of Madagascar described by Lacroix,[4] and named 'bekinkinite' by Rosenbusch.[5] It is considered as a special modification of the Paisley teschenite or dolerite.

The unique character of the rock in British petrography is sufficiently indicated by its identification with bekinkinite, which was formerly only known from the type-locality of Bekinkina in Madagascar. During recent visits to the Barshaw exposure other varieties of the rock were found, principally as schlieren drawn out as thin streaks in the predominant melanocratic or mesocratic variety. These schlieren provide mesocratic and leucocratic facies of the type, and are identical with the rock described as lugarite.[6] In view of the discovery of these varieties, the unique character of the rock, and the fact that the old quarry at Barshaw is on a building site and is being made a dump for refuse, it has been thought advisable to give a full description before the exposure disappears.

Field Relations.

The Barshaw bekinkinite is obtained from an old quarry situated in a plantation a little to the east of Barshaw House, 1½ miles east of Paisley, along the Glasgow road. The opening is very shallow, the greatest depth of rock seen being only 5 feet. The eastern part of the quarry shows a ledge of hard rock, the base of which consists of the melanocratic variety in a rather decomposed condition. Towards the top of the exposure irregular patches and streaks of a light-coloured pinkish rock, crowded with small black prisms and needles, begin to appear. These are usually drawn out into irregular streaks or schlieren, but sometimes form much-involved, irregularly-shaped patches embedded in the darker type. These 'facies de variation' show considerable differences amongst themselves in texture and the relative proportions of the black prismatic minerals (barkevikite and titanaugite), but the general contrast of the pale leucocratic schlieren with the predominant dark, basic, melanocratic type remains the most striking feature of the exposure. In all, including the melanocratic facies and the light-coloured schlieren (lugarite), no fewer than seven distinct varieties of rock may be distinguished by microscopic examination (see Petrography, *postea*). The leucocratic schlieren seem to be more abundant towards the top of the exposure, but the

[1] *Summary of Progress of Geological Survey for 1908*, 1909, p. 44.
[2] *Summary of Progress of Geological Survey for 1907*, 1908, p. 55.
[3] *Geology of the Glasgow District* (Mem. Geol. Surv.), 1911, pp. 116, 134.
[4] Nouv. Arch. Mus. (4), i, p. 135, 1902; ii, p. 227, 1903.
[5] Micr. Phys., ii, p. 441, 1907.
[6] Tyrrell, Geol. Mag., Dec. V, Vol. IX, pp. 77–8, 1912.

amount of rock visible is too small for this fact to have any distributional significance.

In the western corner of the quarry an exposure of decomposed rock shows a band of hard, grey, spotted material (variety No. 7), and three lenticular streaks of the leucocratic variety mentioned above.

The Barshaw exposure forms part of a persistent intrusion which appears near the Hurlet horizon in the Paisley district, and has been named the Hurlet sill.[1] A fine exposure occurs in the railway cutting at Arkleston, another at the Blackhall Quarry, and the River Cart near by. Exposures also occur at Seedhills and Old Crookston Farm. All these localities lie to the east of Paisley, and have been fully described by P. Macnair.[2] A sill is also seen in the old quarry at the Fossil Grove, Victoria Place, Whiteinch, on the north side of the Clyde.[3] According to the Geological Survey this exposure belongs to the Hosie sill, a small intrusion from 24 to 30 feet in thickness, which occurs near the Hosie Limestone horizon, about 20 fathoms above the Hurlet sill.[4] Mr. Macnair thinks it highly probable that the Seedhills, Blackhall, Arkleston, and Whiteinch intrusions belong to the same great mass and are connected underground. Mr. R. G. Carruthers also, in the Glasgow Memoir, thinks it probable that the Hosie sill is an offshoot from the Hurlet.

At Arkleston and Blackhall the Hurlet sill has become involved with the Hurlet Coal, and has suffered great endomorphic metamorphism, resulting in that modification the extreme term of which is known as 'white trap'. This mode of alteration is general throughout the mass of the sill, except perhaps in the centre. It is consequently exceedingly difficult to trace any resemblance between these rocks and the Barshaw theralites. If the Barshaw exposure belongs to the Hurlet sill, it has ascended or descended in this area to a horizon devoid of carbonaceous material, and has escaped the 'white trap' mode of alteration.

The determination of the true petrographic character of the Hurlet sill (apart from the Barshaw exposure) is much hindered by its extensive decomposition. The freshest material occurs at Old Crookston Farm and at Hurlet. The latter rock is described in the Geological Survey Memoir on the Glasgow District (p. 133) as an ophitic dolerite with purple augite, abundant olivine, and but little analcite. It is stated to resemble somewhat the Gallaston type of Fife. This description well fits the rock from Old Crookston Farm. My specimen shows numerous areas of chlorite rosettes which doubtless obscure areas of analcite, as they do in other undoubted analcite rocks from the same region. Areas of calcite also occur in polygonal spaces between the felspars in such a way as to suggest that they have replaced analcite. Alkali-felspar (probably soda-orthoclase) may also occasionally be detected in small quantity. The rock from the centre of the Arkleston sill is of the same general character, but is finer-grained, and its augite has a very deep purplish tint. These rocks are very similar to the types termed alkali-dolerite

[1] *Geology of the Glasgow District* (Mem. Geol. Surv.), 1911, p. 116.
[2] Trans. Glasgow Geol. Soc., vol. xiii, pt. i, pp. 58–60, 1907.
[3] Rutley, Q.J.G.S., vol. xlv, pp. 626–32, 1889. [4] Glasgow Memoir, p. 117.

and essexite-dolerite from the Ayrshire province [1] and to the crinanites of Argyllshire and Arran.[2] It is worthy of note that the essexite-dolerites of Ayrshire are intimately associated with certain highly analcitic types.

Mineralogical Description.

All varieties of the Barshaw rocks described later contain the same set of minerals, and differ only in the relative proportions of each. It is therefore convenient to describe the mineral constituents together. These minerals are titanaugite, barkevikite, ægirine, ilmenite, olivine, apatite; nepheline, analcite, plagioclase, orthoclase; with various decomposition-products.

The *titanaugite* is a deeply-coloured variety, with a relatively intense pleochroism, ranging from a clear pale brown to a deep maroon or purple-madder tint. The colours are very patchy in their distribution. Sometimes they form regular zoning parallel with the margin of the crystal, sometimes a good hour-glass structure. More often the tints have no regular distribution; but the different parts are generally separated by a sharp distinct line, and do not fade one into the other. Occasionally there is a narrow exterior zone of green ægirine-augite. The double refraction is high, with strong dispersion of the bisectrices, so that sections parallel to the symmetry-plane do not give complete extinction in white light. It is euhedral to all minerals save olivine and plagioclase. It is often irregularly indented by the terminations of the latter crystals.

The amphibole is a deep red-brown variety, referred to *barkevikite*. It is highly pleochroic, the extremes of colour being clear pale yellow and a deep red-brown. The latter has often a faint purplish shade. There is frequently a very narrow exterior zone of greenish or bluish material (arfvedsonite ?). Many sections have a small irregular core or central interlamellation of titanaugite in parallel intergrowth, and these are undoubtedly primary crystals which have grown upon a core of augite. Most of the barkevikite is primary, and in some of the rocks it is unaccompanied by titanaugite. Where, however, the latter is in excess, as in the melanocratic type, the amphibole forms a more or less broad exterior margin to the augite crystal, having an outer crystalline form, but with extremely ragged, irregular, interior margins against the pyroxene. Here it is clearly an outgrowth upon the pyroxene, not due to weathering, but to molecular instability of the pyroxene during or after crystallization. The barkevikite may enclose the terminations of felspar laths of early crystallization, but both it and the pyroxene is occasionally found enclosed within the later, highly-zonal plagioclase.

Small crystals of deep green *ægirine* occur enclosed in the analcite and nepheline.

Ilmenite occurs in skeletal crystals which frequently have an external euhedral form. It is always partially altered to leucoxene or granular sphene, and frequently presents a barred appearance; or unaltered ilmenite is left as an external zone around a core of

[1] Tyrrell, Geol. Mag., Dec. V, Vol. IX, p. 124, 1912.
[2] Tyrrell, Geol. Mag., Dec. VI, Vol. X, p. 307, 1913.

leucoxene. It presents varying relations to the pyroxenes and amphiboles, and is sometimes moulded on them and sometimes enclosed. All three minerals were crystallizing simultaneously and with nearly the same period of crystallization. The felspar, however, overlaps all the coloured minerals. It began crystallizing before, and finished after them.

Olivine only occurs abundantly in the bekinkinite, and is very rare in the lugarites. It forms rounded crystals, and is invariably altered to a deep-green serpentine.

The groundmass in which the coloured minerals are set is largely a confused mass of greyish alteration-products flecked with green, in which plagioclase, nepheline, and analcite may be identified in the fresher rocks.

The *plagioclase* was originally euhedral, but has now extremely irregular outlines due to intense corrosion by the hot, aqueous, alkaline residues, which subsequently crystallized as nepheline and analcite. The margins of the crystals invariably fade away into the turbid material which constitutes most of the groundmass of the rock. It is markedly zonal, and albite twinning is not well developed. Moreover, the partial or complete analcitization makes measurable extinctions hard to find. In the bekinkinite slides a single measurement gave symmetrical extinction-angles of $30\frac{1}{2}°$ (Ab_1 An_1); and in the lugarites two measurements gave 15 and 20°, indicating a composition near Ab_5 An_3. The analcitization of the felspars is very advanced. The crystals are filled with patches and veins of analcite which has spread in irregular masses from the cleavages.

Orthoclase occurs rather abundantly in the more leucocratic rocks, and generally forms a broad marginal zone to the plagioclase felspars. It is easily distinguished from the nepheline by its different mode of alteration and by its relation to the lime-soda felspars. It is generally in process of decomposition with the formation of a fine greyish dust, which contrasts with the yellowish streaky appearance produced by the alteration of the nepheline.

The *nepheline* is euhedral towards the abundant analcitic groundmass, and in one rock it is euhedral towards orthoclase. It occurs in well-shaped rectangular and hexagonal sections which are largely outlined in a very minute dust, composed of yellowish micaceous scales. This occasionally covers the whole section, but usually alternates in a streaky fashion with colourless and apparently unaltered material. The latter gives extremely low double refraction, and extinguishes in the direction of streakiness. The outlines of the crystals are often lost in decomposition products, producing very irregular fragments. Occasionally the nepheline forms large plates enclosing the other constituents, especially minute crystals of ægirine. The clear portions of the crystals are optically negative in the direction of streakiness, parallel to the longer edges of the rectangular sections. Its refractive index is well below that of Canada balsam, and the mineral is probably identical with the 'nepheline x' of Bailey, which is distinguished from ordinary nepheline by its lower refractive index.[1] Mr. Bailey has also noted the occurrence of 'nepheline x'

[1] *Geology of East Lothian* (Mem. Geol. Surv.), 1910, p. 110.

in one of the Barshaw rocks, as well as in the essexites of Crawfordjohn and Lennoxtown, and the nepheline-teschenite of Catheart.[1]

Another mineral is closely associated with the nepheline, and weathers in much the same way. It is generally intergrown with nepheline in alternating streaks. It differs from nepheline principally in its double refraction, which is apparently a little higher than that of quartz. It polarizes in straw yellow and reddish tints. The mineral has a good cross-fracture, and is optically positive with regard to the direction of elongation, and perpendicular to the cross-fracture. Its refractive index is somewhat higher than that of nepheline. The crystals are occasionally shaped like those of nepheline, giving rise to the suspicion that the mineral may be pseudomorphous after nepheline. Frequently, however, it forms irregular plates, which enclose crowds of small needles of barkevikite.

This mineral appears to be identical with that described by Bailey as associated with 'nepheline x' (East Lothian Memoir, p. 111). Mr. Bailey also states that it occurs in the West of Scotland associated with 'nepheline x', but makes no mention of it in the petrographical chapter of the Glasgow Memoir.

Petrography.

1. The Bekinkinite.—This is the most melanocratic type found at Barshaw, and occurs at the base of the exposure.

The most abundant mineral is titanaugite, usually intergrown with barkevikite. The latter rarely forms independent crystals. The next most abundant mineral is olivine, completely altered to a green serpentine. The iron-ores include ilmenite and pyrite. The subordinate groundmass consists of corroded felspar, altered nepheline, and analcite, the latter occasionally quite fresh. The nepheline forms large anhedral plates, which enclose the minerals of earlier consolidation. The general decomposition of the leucocratic minerals renders the elucidation of their mutual relations rather difficult. The plagioclase is always earlier than the felspathoids, and is invariably corroded, and clearly reacted upon by the hot alkaline solution in which it crystallized. Mr. Bailey believes that the analcite is derived from the alteration of the nepheline.[2] Our rock is too decomposed to give decisive evidence upon this point, but in the other rocks of this series the nepheline is frequently euhedral to the analcite, and does not appear to pass into it. Moreover, the nepheline has its own distinctive mode of alteration. The chemical composition of this rock is shown in the Glasgow Memoir, where it is compared with other Scottish rocks and the type bekinkinites of Madagascar (Glasgow Memoir, p. 134). Its chemical composition is further discussed in this paper (Table I), and its quantitative mineral composition has been determined (Table II).

2. Lugarite.—The six varieties described below may all be grouped together under the term lugarite. This name was applied to a unique rock occurring in the Lugar sill, which may be interpreted as an ijolite in which nepheline is partly or wholly displaced by analcite,

[1] *Geology of Glasgow District* (Mem. Geol. Surv.), 1911, p. 128.
[2] Ibid., p. 134.

and in which barkevikite is a prominent constituent as well as augite.[1] A description of this rock is given in the above cited paper; but since this was published a chemical analysis of the type-rock has been made by Mr. Alex. Scott (Table I) which fully bears out its diagnosis as a new type. Mr. Scott has also executed an analysis of the Barshaw lugarite (Table I), which shows a very close resemblance to the type-rock of Lugar. The quantitative mineral composition of some of these rocks is shown in Table II.

Variety 1.—This rock occurs about the middle of the Barshaw exposure, overlying the bekinkinite. It is decidedly less melanocratic than the latter rock, as is shown in Table II. It may be described as a mesocratic facies, in which there is approximate equality between the lighter and darker constituents. It is characterized by the abundance of equidimensional and euhedral titanaugite, which is of a highly pleochroic variety. Outgrowths of barkevikite occur, but are comparatively rare, whilst ilmenite, in process of alteration to leucoxene, has increased in amount as compared with the bekinkinite. The leucocratic groundmass is much altered, but large patches of orthoclase may be seen, as well as areas of analcite which frequently shows anomalous birefringence. The nepheline is completely altered to a dusty yellowish material. Very faint 'ghosts' of plagioclase felspars occur in the turbid groundmass.

Variety 2.—This variety forms the major portion of the schlieren towards the top of the exposure. It is an even-grained mesocratic rock characterized by the abundance of red euhedral barkevikite, as well as the purple titanaugite, often in intergrowth. The groundmass in this rock is comparatively fresh. In it may be recognized clear, fresh plagioclase, often corroded and traversed by anastomosing veins of analcite. The felspar crystals are often eaten out by analcite, leaving very ragged remains embedded in the latter mineral. Orthoclase occurs rather abundantly, either as marginal zones to the plagioclase felspars, or much altered and only recognizable in small clear patches surrounded by various alteration products. Nepheline occurs in broad anhedral plates with the characteristic streaky alteration, and poikilitically enclosing the earlier constituents. There is some clear interstitial analcite. When enclosed in nepheline the pyroxene becomes a variety close to ægirine; and the crystals of titanaugite always have a narrow green marginal zone where they abut on nepheline or analcite. The nepheline, and the leucocratic groundmass in general, is riddled with needles of apatite. This rock differs from the preceding only in that the quantitative relations of titanaugite and barkevikite are reversed (Table II).

Variety 3.—This occurs in schlieren along with the preceding type. It is a rock of a pinkish colour, and containing black prisms of barkevikite. In thin section it is seen to be a leucocratic development of the preceding variety. The ferromagnesian minerals have dwindled in quantity and size. Titanaugite has totally disappeared, and barkevikite alone is left in any quantity. On the other hand there is a development of minute prisms of ægirine-augite, enclosed

[1] Tyrrell, GEOL. MAG., Dec. V, Vol. IX, pp. 77–8, 1912.

in the felsic constituents. Ilmenite is present, but in very small amount. Amongst the predominant felsic or leucocratic minerals nepheline is the most conspicuous. It occurs in well-formed crystals which are euhedral toward analcite and orthoclase, but not to plagioclase. Orthoclase is more prominent than plagioclase, whilst the latter is highly analcitized. Analcite, with anomalous double refraction, fills up the interspaces.

Variety 4.—This occurs closely associated with the two preceding varieties in thin streaks or schlieren that have been drawn out together during intrusion. It is chiefly distinguished from variety 3, which it closely resembles otherwise, by its much finer grain. Barkevikite is especially prominent in small prisms, and is intergrown in very irregular fashion with titanaugite. This, and the succeeding variety, are little more than textural modifications of varieties 2 and 3.

Variety 5.—This schlier resembles variety 4 in granularity and generally in mineral content, but is devoid of titanaugite. The barkevikite has an acicular habit which makes this a striking and easily recognized type. In the hand-specimens the barkevikite forms numerous black needles embedded in a pinkish groundmass. This rock is rich in nepheline, and in the unknown mineral which resembles and occurs along with the nepheline. The nepheline is well-shaped and is usually crowded with prisms of barkevikite. Analcite occurs in considerable quantity, and orthoclase is dominant over plagioclase.

Variety 6.—This is a white-spotted rock from the exposure on the west side of the quarry, and is characterized by its richness in small, perfectly euhedral crystals of titanaugite. Barkevikite is in subordinate quantity. The rock is also characterized by containing more or less rounded areas of the felsic minerals, almost completely devoid of the coloured constituents. These appear as white spots in the hand-specimens and slides. Growths of chlorite rosettes occasionally form some proportion of these spots, and probably replace analcite. This rock appears to be a textural modification of variety 2.

(*To be concluded in August Number.*)

IV.—On a Marine Band in Middle Coal-measures, South Lancashire.

By R. L. Sherlock, D.Sc., A.R.C.S., F.G.S.

Up to the present marine fossils have been recorded in Middle Coal-measures in the South Lancashire Coal-field at two horizons only. They are (1) in the banks of the Tame, near Ashton-under-Lyne, found by Professor A. H. Green,[1] and at Ashton Moss Colliery, about 750 feet above the Great Mine, discovered by the late George Wild.[2] (2) Mr. H. Bolton, F.R.S.E., informs me that the Californian or Thin Bed of Fulledge Colliery, Burnley, which is 410 feet above the Arley Mine, is a marine horizon.

Mr. John Gerrard, in his Presidential Address to the Manchester Geological and Mining Society,[3] mentioned a marine band found at

[1] E. Hull, *Geology of the Country around Oldham* (Mem. Geol. Surv.), 1864.
[2] J. Gerrard, Trans. Inst. Min. Eng., vol. xxviii, p. 363, 1904. [3] Ibid.

Victoria Colliery, Standish, as probably near to the Arley Mine. He tells me that he is now of opinion that the strata were faulted and that the marine horizon really belongs to the Lower Coal-measures. So far as I know, there is no record of marine fossils in the Middle Coal-measures of the western part of the coal-field.

Recently, while examining a collection I made about the year 1890, I found a small slab of shale containing numerous marine fossils. The specimen was found on the tip-heap of the Alexandra Colliery, not many yards south-west of the Ravenhead Plate Glass Works, St. Helens. The shaft is situated on the outcrop of the Ravenhead Main Coal, according to the Geological Survey Map, and was sunk to the Little Delph (Arley Mine). The horizon of the marine band will therefore be somewhere between the Little Delph and the Ravenhead Main Coal, and it is probable that the fossils came from the roof of the Little Delph (Arley Mine). Mr. John Gerrard, who has a special knowledge of these strata and has examined the fossils, considers that the character of the stone confirms this idea. The specimen is a fragment of hard black shale, crowded with organic remains, many of them indeterminable, but amongst them *Pterinopecten papyraceus* (J. Sow.) and Goniatites are readily identifiable. A number of pieces of black shale collected at the same time and place, and similar to the fragment just mentioned, although looking somewhat less weathered, contained abundant fish-remains. Many of these were very fragmentary, but others have been named by Mr. W. Manson, who has compiled the following list:—

On a single fragment of shale—

Pterinopecten papyraceus (J. Sow.).
Gastrioceras sp.
Orbiculoidea?

The following are on similar black shale collected at the same time and place:—

Elonichthys aitkeni, Traquair (fine specimen).
Rhizodopsis sauroides (Will) (scale).
Megalichthys hibberti? Ag. (scales and teeth).
Cœlacanthus sp.
Lepidostrobus variabilis? L. & H. (with fish-remains on the back).
Lepidodendron (with fish-remains on the back).

The specimens will be deposited in the St. Helens Corporation Museum.

In conclusion I wish to express my thanks to Mr. John Gerrard for the helpful information which he has given me.

V.—The Relation of the Coal-measures to the Lower Carboniferous Rocks in the Clapton–Clevedon District, Somersetshire.

By Frank Dixey, B.Sc., F.G.S., Assistant Lecturer in Geology, University College, Cardiff.

THIS paper gives the results of investigations made during the early part of the present year with the object of elucidating the relation of the Coal-measures to the Lower Carboniferous rocks in the Clapton and Clevedon districts of Somersetshire.

The Carboniferous Limestone forms a ridge which extends eastwards from Clevedon to beyond Clapton in Gordano. On the northern flank of this ridge lie two separate outliers of Coal-measures. In the east, around Clapton in Gordano, the Coal-measures cover a considerable area and constitute the Clapton Coal-field, but in the west their outcrop forms only a narrow discontinuous strip which extends as far as Clevedon.

A glance at the Geological Survey map [1] of this district shows that the relation between the Lower and Upper Carboniferous is an abnormal one. In the neighbourhood of Clapton in Gordano, the southern boundary of the Coal-measures transgresses the outcrops of the Carboniferous Limestone, the Lower Limestone Shales, and the Old Red Sandstone, and the Coal-measures enclose several small patches of Carboniferous Limestone. Moreover, whereas the Lower Carboniferous and older strata possess a variable but persistent southern dip, the Coal-measures dip to the north and north-west.

In the Geological Survey memoir on East Somerset and the Bristol Coal-fields,[2] the Coal-measures of the Clapton area are assigned mainly to the Pennant Grit or Middle Series of the Bristol and Somerset Coal-fields. The only reference made to the anomalous relation of the Coal-measures and the Carboniferous Limestone is contained in the following passage [3]: "Around Clapton in Gordano are several patches of Carboniferous Limestone occurring in the midst of Coal-measures, positions which it seems difficult to account for."

Professor C. Lloyd Morgan maintained [4] that the small isolated masses of Carboniferous Limestone are the remnants of a sheet of Carboniferous Limestone which was carried down over the Coal-measures by a "flat-lying fault".

Dr. A. Vaughan, however, in his paper on the Carboniferous Limestone of the Bristol area,[5] wrote as follows: "I am strongly inclined to believe that there is, in this region, evidence of post-Tournaisian upheaval and denudation, and that the area was not again submerged until the Coal-measures were laid down in a narrow inlet, bounded on the west by the Clevedon–Portishead ridge and on the south by the western part of the Clevedon–Failand ridge. Within this inlet, the masses of Carboniferous Limestone in the Clapton district stood up as small islands."

My own observations in this district confirm the unconformable relation of the Coal-measures to the Lower Carboniferous and the Old Red Sandstone. It is evident that, in Carboniferous times, the district suffered not only considerable folding, but also much faulting, as shown by the relative position of the 'islands' and main outcrop of the Carboniferous Limestone.

[1] Sheet 19 (Old Series), Somersetshire.

[2] *Geology of East Somerset and the Bristol Coalfields* (Mem. Geol. Surv.), 1876, p. 45.

[3] Ibid., p. 42.

[4] "Geology of the Avon Basin (Portbury and Clapton Districts)": Proc. Bristol Nat. Soc., N.S., vol. v, 1885–8, p. 44.

[5] "Palæontological Sequence in the Bristol area": Q.J.G.S., vol. lxi, 1905, p. 232.

Unconformity between the Coal-measures and the Lower Carboniferous has recently been demonstrated in the Titterstone Clee Hills by Mr. E. E. L. Dixon,[1] and in the Forest of Dean Coal-field by Professor T. Franklin Sibly.[2]

This investigation was undertaken at Professor Sibly's suggestion, and I have great pleasure in recording my indebtedness to him for advice and helpful criticism.

Review of Field Evidence.

Eastern District (*The Clapton Coal-field*).

This area has been mapped on the scale of 6 inches to 1 mile. It furnishes conclusive evidence of unconformity between the Coal-measures and the older strata. On the north the Coal-measures sink beneath the Trias, but on the east and south they are bounded by the Old Red Sandstone and the Carboniferous Limestone Series. The unconformity may be demonstrated in three ways: (1) By the overstep of the Coal-measures from the Carboniferous Limestone across the Lower Limestone Shales on to the Old Red Sandstone. (2) By the occurrence of small 'islands' of Carboniferous Limestone which rise through a covering of Coal-measures. (3) By angular discordance between the Coal-measures and Carboniferous Limestone; this is suggested by the general northerly dip of the Coal-measures and southerly dip of the older rocks, and it is proved by small exposures in the neighbourhood of Clapton Church (St. Michael's).

1. The southern and eastern boundary of the Coal-measures has been carefully traced. Its transgressive nature is quite evident from the map, and the overstep can be definitely proved on the ground immediately south and east of Naish House. Near Naish House the boundary gradually crosses from the Carboniferous Limestone, the base of which continues as a low escarpment due east towards Moat House Farm, on to the Lower Limestone Shales. It extends a short distance eastwards along the little strike valley in the Lower Limestone Shales (where a spring is thrown out from the Pennant Grit by the underlying Lower Limestone Shales), and then swings northward somewhat suddenly until the Coal-measures rest directly upon the Old Red Sandstone.

2. The 'islands' of Carboniferous Limestone usually form little rounded and wooded knolls. The largest, that immediately west of Clapton village, lies on the margin of the Coal-measures, and is for the most part surrounded by Trias. The other knolls, five in number, are situated within less than a mile to the south-west; three of them are entirely, and a fourth is partly, enclosed by Coal-measures. The small knoll upon which St. Michael's Church stands is bounded on all sides by the Coal-measures, which are clearly seen in several places to rest upon the Limestone.

3. The unconformable junction between the Coal-measures and the Carboniferous Limestone is best seen in a small excavation on the eastern side of the field path which leads northwards from the

[1] Geol. Mag., Dec. V, Vol. VII, p. 458, 1910.
[2] Geol. Mag., Dec. V, Vol. IX, p. 420, 1912.

GEOLOGICAL MAP OF
THE CLAPTON DISTRICT
SCALE: 3 INCHES TO 1 MILE.
CONTOUR-LINES
ALLUVIUM.
TRIAS.
COAL MEASURES.
CARBONIFEROUS LIMESTONE. LOWER LIMESTONE SHALES.
SANDSTONE. CONGLOMERATE
O.R.S.
C.M.
CLAPTON
BORDANO
NAISH HOUSE
ST MICHAEL'S CHURCH
MOAT HOUSE FARM
100
200
300
400
500
50

churchyard. Here flaggy sandstones with a low southerly dip rest upon an irregular surface of massive limestone. These sandstones are coarse in texture and highly calcareous, and, like most of the Pennant Grit of this district occurring at a low altitude, have been stained red by the Keuper which once overlay them. The angular discordance is demonstrable in a small exposure at the foot of an ash-tree, half-way down the steep bank between the north-west wall of the churchyard and the road. The Pennant here shows the same dip as in the previous section, and in this case the underlying limestone can be clearly seen to dip southward at a larger angle. Although the actual junction is not well defined at any other point, there are numerous very small exposures of both Pennant and Carboniferous Limestone on the northern and western sides of the knoll upon which the church is built; and apart from its occurrence in the section described, angular discordance is indicated by the dips shown in all these closely adjacent exposures. It is of interest to trace within about 50 yards the gradual passage of the calcareous and highly stained sandstone to the normal blue-grey Pennant Flagstone. On the western side of the church is a deep cutting running to the south and east, in which this change can be followed. Sandstones precisely similar to those seen resting on the limestone close to the churchyard are found to lose their calcareous character and rich staining when they are traced southwards, and, moreover, plant-remains become abundant.

Western District (*Clevedon Area*).

This district includes the Coal-measures exposed on Strawberry Hill and Court Hill, near Clevedon. The original relation of these to the older rocks has been masked by faulting, which has brought the Coal-measures against the Carboniferous Limestone, and the fault can be traced directly down the steep slopes of the gap which separates the two hills. The faulting is doubtless connected with the profound disturbances that gave rise to the two ridges of Carboniferous Limestone which converge at Clevedon. I hope to continue my investigation of the geological structure of this area.

VI.—Studies in Edrioasteroidea, VIII. A Comparison with the Structure of Asterozoa.

By F. A. Bather, M.A., D.Sc., F.R.S.

Published by permission of the Trustees of the British Museum.

THE resemblance of the oral face of an Edrioasteroid to an Asteroid has not merely been remarked on by nearly every writer on the group, but has led many of them to far-reaching conclusions (e.g. Steinmann, 1888; Neumayr, 1889). None the less no exact comparison of the structures has yet been made; nor indeed was such possible until accurate descriptions were available. These have now been provided for various recent and fossil Asterozoa by many writers referred to in the sequel, and especially by Mr. W. K. Spencer (1914, "Monogr. Brit. Palæoz. Asterozoa"; Palæontogr. Soc.).

In general shape the Edrioasteroidea are more rounded and less stellate than the starfish. This is a natural consequence of the mode of life of the two classes. The Edrioasteroid that appears to have been the least sedentary, namely *Stromatocystis*, is also the most stellate. Similarly in Asteroidea the active Asteriidæ have, as a rule, longer arms than the more sluggish Asterinidæ and Echinasteridæ. Mere outline, then, has little genetic significance; the distinction, if any, lies in the large development of interambulacral plates in the Edrioasteroidea and their lack of marginalia, for the 'marginals' of *Agelacrinus* are scarcely homologous with those of Asteroidea. The observations of Mr. Spencer, however, "show that the most primitive Asterozoa have a leathery skin in which are imbedded small irregular plates" (p. 34), and that many of them "are devoid of differentiated marginalia" (p. 20). The specialization of the irregular plates into marginalia or other skeletal elements differed in the different branches of Asterozoa (Spencer, p. 8), just as it differed in the various genera of Edrioasteroidea. The ossicles of fundamental importance are those which were "the first to be laid down" or, at any rate, to be specialized from the indifferent coating of plates, namely, "those associated with the water-vascular system (ossicles of the ambulacral groove and mouth-frame)." It is to these, then, that our attention must be directed.

In the older Asterozoa, from which the true Asteroidea and Ophiuroidea were derived, the plates which in a modern starfish are known as "Ambulacralia" were "little more than mere flooring plates to the ambulacral grove" (Spencer, p. 21). They formed a double series, either opposed as in recent Asteroidea, or alternating as in *Edrioaster*. Spencer, following Gregory and Jaekel, regards the latter arrangement as the more primitive. These ambulacrals were approximately rectangular in plan, and excavated along the perradial sutures by a shallow "ambulacral channel" for the radial water-vessel. Along the sutures at right-angles to this the plates were deeply excavate, leaving a well-marked median transverse ridge along each. The longitudinal ridge, parallel to the ambulacral channel, was but slight, indicating the feeble development of the transverse ventral muscles.

Thus far the description is equally applicable to *Edrioaster*, but the difference from both *Edrioaster* and the true Asteroidea lies in the alleged absence of podial pores. It is presumed that branches led from the perradial water-vessel to podia placed somewhere in the depressions between the ridges; and it is possible that these depressions indicate the presence of incipient ampullæ; but, according to Mr. Spencer, the ampullæ had not yet penetrated to the interior. Were that view correct, *Edrioaster* itself would be more advanced in this respect than the older Palæozoic Asterozoa, and would find its analogue in such a form as the Lower Devonian *Xenaster*, where the pores have the same relative size and position (see Schöndorf, 1909, Palæontographica, vol. 56, pl. xi, fig. 2).

In reference to the earlier Asterozoa, Mr. Spencer says (p. 18): "Many investigators, owing to the poor state of preservation of their material, have described these depressions as pores for the

passage of ampullæ." This is probably true, and yet it does not follow that pores were not developed before Devonian time, or even that they were absent in the very cases to which Mr. Spencer refers. The true pores in *Xenaster* are difficult to see, by reason both of their position and their small size; they were probably even more difficult to see in the predecessors of *Xenaster*. Take *Lindstromaster*, for instance, from the Wenlockian of Gotland. Dr. J. W. Gregory, in his exceedingly succinct account (GEOL. MAG., 1899, p. 347), said: "The ambulacral plates are boot-shaped. The pores for the podia are large." Apparently these statements were based on plates in which the depression was still partly filled by matrix. In other regions, however, the matrix has been most carefully removed, and the true structure is represented in Liljevall's accurate drawing (GEOL. MAG., 1899, pl. xvi, fig. 1*b*, the ray in the south-east position, on the west and east sides of it respectively). The details are obscured in the half-tone reproduction, but I had the opportunity of comparing the original with the specimen itself in special reference to this point. The median ridges of the floor-plates run diagonally from the proximal adradial corner to the distal outer corner of each plate, so that, if the sutures be not carefully observed, the plates appear to be directed distalwards as they pass outwards. The sutures, however, really pass in the contrary direction. Thus the position where the pore should be looked for is where the suture meets the outer end of the ridge. Here the pore is indicated by Liljevall, almost hidden by the ridge and the overhanging "adambulacral", and here it does seem really to occur in the specimen, though proof by sections or grinding down is wanting.

If pores were absent in all the pre-Devonian Asterozoa, it would be very difficult to understand how the relatively narrow pores of *Xenaster* were formed. Starting with pressure of an incipient ampulla outside the floor-plates, one would expect to observe a gradual deepening of the excavation until it broke through into the thecal cavity as a relatively wide hole. Such is in fact the appearance presented by Professor Jaekel's drawing of *Siluraster perfectus*, from the uppermost Ordovician of Bohemia (November, 1903; Zeitschr. deutsch. Geol. Gesell., vol. 55, Protokoll. p. 108=p. 15). As our knowledge increases it may be that we shall find among the early Asterozoa, as among the Edrioasteroidea, some genera with podial pores, others without, forming parallel lines of descent. The presence of endothecal ampullae is necessarily dependent on the existence in the rays of a thecal cavity large enough to contain them.

The Cover-plates of *Edrioaster* appear to find their homologue in the so-called "Adambulacralia" of the starfish. These elements are thus described by Spencer in *Archaster typicus* (p. 13): "They are irregularly pentagonal in shape. The outer side runs almost parallel with the length of the groove. The face nearest to the groove has two facets [i.e. two sides of the pentagon]. The proximal facet is short and straight, the distal facet somewhat longer and slightly concave. We shall see that the appearance thus presented is characteristic of primitive Asterozoa and primitive Ophiuroidea as well as of the Asteroidea." This description applies almost exactly

to the cover-plates of *Edrioaster*, as may best be seen by a comparison with Text-figure 2 of Study IV (1914, p. 164). The difference lies in the greater development of articulating muscles and their surfaces of attachment in *Archaster*, especially in the fact that the adambulacrals are united to each other by a longitudinal muscle. It may also be noted that in *Archaster* each adambulacral is attached to two ambulacrals (floor-plates); Mr. Spencer, however, points out that the attachments are not really equal, as so frequently implied for this and other modern asteroids, but that one of the attachments preponderates and "connects the ambulacral to the adambulacral with which it corresponds in the series". In the early Palæozoic Asteroidea each ambulacral is associated only with its own adambulacral, just as in *Edrioaster* each floor-plate has its cover-plate. In these early forms also, as appears from the descriptions of Schöndorf, Hudson, and Spencer, the articulating sculpture and muscle-connections were much less developed.

The cover-plates of the Agelacrinidæ, recently so well described by Dr. Foerste (1914, §§ 16 and 22) are in some respects even more like Asteroid adambulacrals. The inequality of the admedian sides ('facets' W.K.S., *loc. cit.*) is generally exaggerated, so that in plan the visible portion of the cover-plate "has a spinous prolongation on the proximal side" (Foerste), or is "shaped like a bent finger" (Spencer, 1904), or is what J. W. Gregory calls 'boot-shaped', with the sole towards the mouth. Further, as Foerste has shown, in many of the Ordovician species the vertical section of a cover-plate is roughly sickle-shaped (or boomerang-shaped), the blade corresponding to the part which arches over the groove, and the handle to a narrower extension beneath the adjacent interambulacrals. Where blade and handle join is a slight groove between two ridges, forming an articulation with the floor-plate. Similar passage of the adambulacrals beneath the adjacent interambulacral (ventro-lateral) plates may be seen in many modern starfish. The chief difference is that the cover-plates of Agelacrinidæ are not one to each floor-plate; but this doubtless is due to the fusion of the floor-plates into groups, as already explained.

The adambulacrals of starfish do not close down over the groove in the same way as did the cover-plates of *Edrioaster*, and the contents of the groove are generally protected by groove-spines borne on the adradial margin of the adambulacral plates. None the less, by the approximation of the two sides of the groove, effected by the ventral cross-muscles, the adambulacrals may be brought quite close together, and in some species they may when thus closed be observed to alternate just like the cover-plates of an Edrioasteroid. See, for example, Ludwig, 1905, "Asteroidea of the Albatross," Mem. Mus. Comp. Zool. Harvard, vol. 33, fig. 51, *Pentagonaster ernesti*, fig. 135, *Paulia horrida*; Koehler, 1910, "Shallow-water Ast. Indian Mus.," pl. xi, fig. 3, *Pentaceros indicus*, pl. xii, fig. 2, *P. reinhardti*, and others; Gregory, 1899, op. cit. fig. 1*b*, *Lindstromaster*, the ray in the north-west position.

The alleged invariable presence of groove-spines, and the frequent presence of other spines on the adambulacrals of Asteroidea does not

constitute any serious difference. Spines were borne by the cover-plates in *Pyrgocystis sardesoni*, and reason has been given for supposing that they occurred in some other species of Edrioasteroidea. But since the cover-plates were in themselves sufficient protection for the grooves, there was not the same need for spines as arose in starfish with their more open grooves.

The Mouth-Frame of a modern starfish consists of five sets of paired radially placed elements and five sets of paired interradially placed elements. The latter, known as the "mouth-angle plates", are continuous with the adambulacrals, and are generally considered to be serially homologous with them. At any rate, they probably contain adambulacral elements, even if they may have incorporated some other constituent. The radially placed elements are admittedly ambulacrals (floor-plates) slightly modified. Morphologically then all these elements belong to the skeleton of the radial grooves. There is, however, another element, the so-called 'odontophore', lying in each interradius and abutting on the mouth-angle plates; whatever its ultimate origin, it presents the appearance of an unpaired interradial element.

For the present purpose it is quite unnecessary to enter into the perennial discussion as to the precise homologies of all these plates in Recent Asteroidea and Ophiuroidea. Comparison need be made only with the early Palæozoic Asterozoa, and here the problem is much simpler.

As an example of a very primitive mouth-frame Mr. Spencer (1914, p. 30) takes the fossil which he names *Eoactis simplex*.[1] His drawing (pl. i, fig. 4) shows a simple series of ambulacrals and of adambulacrals. At the proximal end of the groove the ambulacrals diverge, and the series is there terminated on each side by a curved subtriangular plate, which Mr. Spencer designates "mouth-angle plate". It is, however, clear from his drawing, no less than from the specimen itself, that this plate continues the ambulacral series and not the adambulacral, and this is further emphasized by the fact that the depression for the first podium lies equally on this plate and on the adjacent ambulacral. Further examination of other interradii in the fossil shows that this ambulacral mouth-angle plate was actually overlaid by a paired adambulacral element, though only the empty space that might have been occupied by such a plate is shown in the drawing. It follows from this that the plates marked by Mr. Spencer as A_1 and Ad_1 were really A_2 and Ad_2, and that the true proximal ambulacral and its corresponding adambulacral had not yet fused to form a mouth-angle plate. The continuity of the mouth-angle plate with the ambulacral series is also well illustrated by Spencer's drawing of those parts in *Stenaster obtusus* (1914, p. 32, text-fig. 28).

Turn now to the "series of schemes of buccal armatures of Palæozoic Ophiurids", published by Professor and Miss Sollas (1912, Phil. Trans., vol. 202, p. 226), and to Spencer's figure of *Lapworthura*

[1] This specimen, now in the British Museum, regd. E 13154, was No. 657 of the G. H. Morton collection, and comes from the Lower Ludlow or Upper Wenlock Beds of Hafod, Llandovery.

(1914, pl. i, fig. 9), and Jaekel's diagram of *Eophiura*, *Palaeura*, and *Bohemura* (1903), and it will be seen that the older the form, the more obvious is the composition of the mouth-frame from a series of ambulacrals diverging and becoming overlapped by the corresponding adambulacrals.

Perhaps the most instructive figure in this respect is that of the mouth-angle of *Siluraster perfectus* from the Upper Ordovician of Bohemia (Jaekel, 1903, fig. 3). Here is seen a series of adambulacrals each articulated with its corresponding ambulacral. The proximal adambulacral is enlarged to form a "Mundeckstück", but beneath it is still the ambulacral, though correspondingly reduced in size.

It seems a legitimate inference that all these plans of mouth-frame have been derived from one just a little simpler than the simplest of them, namely, a plan in which the ambulacrals were continuous right round the angle from ray to ray, each accompanied by its adambulacral. At first, no doubt, they were undifferentiated, so that the particular numerals attached to them, either here or in later forms, have no profound significance. Such a simple plan is essentially that of *Edrioaster* (Study IV, 1914, p. 164, Pl. xiv, fig. 2), but here already there is a condensation of the interradially placed floor-plates into a mouth-angle plate, a divergence of the proximal floor-plates of the groove, and an overlap producing in oral aspect the deceptive appearance of distinct perradial elements. The chief point of difference from any primitive Asterozoön lies in the fact that the adambulacrals of *Edrioaster* are still serving their primitive function as cover-plates.

The structure of *Edrioaster* suggests that even the interradially placed odontophore may be not of true interradial or interambulacral origin, but derived from the outer fused portion of the interradially placed floor-plates. On the other hand it is not quite certain that in *Edrioaster* itself this portion may not be in part an interambulacral with which the floor-plates have fused.

The curiously close resemblance between the ambulacral and peristomial structures of an Edrioasterid and those of a primitive Asterozoön would be strange indeed if their modes of feeding had been as different as those usually connoted by the names Pelmatozoön and Asteroid. We have, however, seen reason to believe that *Edrioaster* and *Dinocystis* were not permanently fixed; whence it may be inferred that they possessed some slight power of independent locomotion, towards which movements of the peripheral podia may have contributed. The existence of well-developed podia (a fact that cannot reasonably be doubted) further renders it probable that those organs helped in the transport of the larger food-particles to the mouth. Some Asteroids, on the other hand, and even some Ophiuroids, can use their podia for the same purpose; and some of the less active and less rapacious Asteroids can, as Dr. Gemmill has lately proved, subsist in part, if not entirely, by ciliary nutrition (March, 1915, Proc. Zool. Soc., pp. 1–19). Though a predatory mode of life was assumed at least as early as Devonian times by some starfishes with well-developed mouth-frame, e.g. *Xenaster eucharis* (see J. M. Clarke, 1912, Journ. Acad. Nat. Sci. Philadelphia, ser. 2, vol. 15,

pp. 115–18, pls. xiv–xvi), it is natural to suppose that the ciliary and podial method was that chiefly practised by those earlier Asterozoa in which the mouth-frame was still but slightly differentiated.

We have now reached this stage of our discussion: we have seen, on the one hand, that by the middle of the Ordovician Epoch certain Pelmatozoa had acquired a structure of the rays and of the peristome strangely like that of the Asteroidea; and, on the other hand, that the Asteroidea and, to a less extent, the Ophiuroidea, as they are traced back through the geological periods, approach more and more in the same respect to the structure of the Edrioasteridæ. The conclusion that suggests itself is obvious, but not necessarily correct. Many difficulties have to be smoothed away before a genetic filiation between the two groups can be maintained.

The statement, for instance, that Asteroidea occur in the Cambrian is frequently made, and is always quoted by those who regard the Starfish as a very primitive group, or who deny the possibility of their descent from a form similar to any Edrioasteroid. So long as the term Cambrian was extended to the summit of the Caradocian, the statement was admissible. Nowadays it is misleading. No Asterozoa are yet known below the Middle Ordovician; Edrioasteroidea are known from the Middle Cambrian, and typical Edrioasteridæ were contemporaries of the earliest known Starfish.

Other difficulties are presented by differences of structure and by certain features of the development. These will form the subject of the next Study.

VII.—A Contribution to the Petrology of North-Western Angola.

By Arthur Holmes, B.Sc., A.R.C.S., F.G.S., F.R.G.S.

(*Continued from the June Number, p. 272.*[1])

5. Post-Cretaceous Alkaline Rocks between Senza do Itombe and Bango, Loanda.

THE rocks described below were collected by Colonel Andrade, in 1904, on the road which begins at Senza do Itombe on the Loanda-Malanji Railway, and runs in a north-easterly direction to Bango. The localities, which lie strictly on the road itself, are determined by the following kilometre marks, measured from Senza:—

	km.
Nepheline syenite (foyaite)	near 24
Nepheline phonolite (brown)	,, 22
Olivine ulrichite (camptonitic tinguaite) . . .	,, 20
Nepheline monchiquite (olivine-free)	,, 20
Nepheline phonolite (grey)	between 16 and 17

The intrusive rocks penetrate the Cretaceous formations of the district, which gradually die out towards Bango, where the Archæan

[1] In the Explanation of Plate XI, p. 272, the following corrections should be made: Fig. 3, for "wisp-like ferns" read "wisp-like forms"; Fig. 4, for "Phenolite" read "Phonolite"; for "magnification 40 in each case" read "magnification as indicated in each case".

platform reappears. The phonolites lie on the Cretaceous beds, but unfortunately their relations to the other members of the igneous suite has not yet been determined, and no order of intrusion can be stated. The whole suite of rocks is of post-Cretaceous and probably of Tertiary age. They have not, however, been seen in contact with Eocene or Miocene formations, which, although strongly developed on the west, are not now represented to the north-east of Senza.

Nepheline syenite[1] (Foyaite type).—In the hand-specimen the rock is seen to be made up chiefly of tabular felspars with conspicuous Carlsbad twinning, and nepheline. The felspar is white and grey in colour and the nepheline is similar, but sometimes exhibits a warmer tint. Idiomorphic crystals of pyroxene and sphene are scattered sparsely through the rock, making up less than 10 per cent of the whole.

The mineral composition as seen under the microscope is as follows. On the left the order is that of relative abundance; on the right it is that of crystallization.

Orthoclase and microperthite.	Zircon and apatite.
Nepheline and ægirine-augite.	Sphene and ilmenite.
Cancrinite.	Ægirine-augite.
Sphene and amphiboles (including hastingsite).	Biotite.
Apatite.	Amphiboles and nepheline.
Ilmenite and biotite.	Cancrinite.
Zircon.	Orthoclase and microperthite.

The *felspar* is almost entirely orthoclase, the proportion of perthitically intergrown albite being small. Carlsbad twinning is common, and most of the felspars are turbid, especially along cracks and cleavages, owing to the development of minute scales of sericite.

Nepheline is fresh and clear, though along the more conspicuous cracks micaceous alteration products are present. It is frequently idiomorphic towards orthoclase, and sometimes towards amphibole. *Cancrinite* is associated in small amount with the nepheline, occurring in parallel growth with the latter, or in irregular veins which traverse it. It can be easily distinguished from nepheline by its inferior refractive index and superior birefringence.

The coloured and accessory minerals have a strong tendency to aggregate together in groups, the chief members of which are ægirine-augite and sphene. *Ægirine-augite* occurs in well-shaped crystals, the central parts of which approximate to augite with a grey-green colour, or more rarely to titaniferous augite with a faint purple tint and a slight pleochroism. The outer borders are, however, of a bright green colour, and belong more nearly to ægirine proper than the main mass of the interiors.

Around these pyroxenes, and also around inclusions of magnetite or ilmenite within them, there is usually an irregular border of amphibole, the properties of which point to its being *hastingsite*.[2] The pleochroism and optical orientation are as follows:—

[1] Plate XI, Fig. 2.

[2] Adams & Barlow, *The Haliburton and Bancroft Areas* (Geol. Surv. Canada), 1910, p. 247. Quensel, Bull. Geol. Inst. Upsala, xii, p. 145, 1914.

X, near to a	brown-green	$Z > Y > X$
Y, near to c	blue-green	
$Z = b$	olive-green	

The extinction angle $Y \wedge c$ reaches a maximum of 35°. The birefringence is exceedingly low, being less than that of quartz, but on account of the strong axial dispersion the interference figure is coloured. The axial plane is at right angles to the plane of symmetry, and the optic axial angle is unusually small for an amphibole. Associated with the hastingsite are small patches of another hornblende, having a somewhat higher birefringence and a strong pleochroism, from olive-green to a pale ruddy or yellowish brown. It probably belongs to the arfvedsonite-katoforite series.

Sphene occurs in good lozenge-shaped crystals, which are almost invariably twinned. The pleochroism is from clove to grey. Sphene, and ilmenite in small grains, occur as inclusions in ægirine-augite and hastingsite. Small zircons and apatites, though few in number, are constant accessories, and occur as inclusions not only in the more abundant minerals but also in ilmenite. Tiny shreds of biotite, pleochroic from green to yellow, occur here and there as inclusions in orthoclase or microperthite.

The Mount Jombo (south-west of Mombasa) nepheline syenite[1] is strikingly similar to the Angola rock in structure and mineral composition, and both belong to the foyaite type as restricted by Brögger,[2] and bear a close resemblance to the type-rock of Foya.

Nepheline monchiquite.[3]—In the hand-specimen this rock has the characteristic aspect of a melanocratic rock, showing prismatic crystals of dark-brown hornblende up to half an inch in length embedded in a blue-grey aphanitic groundmass.

The minerals present, as seen under the microscope, are as follows, in order of abundance:—

Phenocrysts.	*Groundmass.*
Pyroxenes.	
Titaniferous augite.	
Ægirine-augite.	Nepheline.
Ægirine.	Analcime.
Augite.	Cancrinite.
Amphiboles.	Pyroxenes.
Barkevikite.	Amphiboles.
Arfvedsonite.	Apatite.
Hastingsite.	Ilmenite.
Sphene.	
Nepheline.	
Analcime.	

As indicated above, the *pyroxenes* form a connected series ranging from augite and titaniferous augite to ægirine-augite and pure ægirine. The largest crystals are idiomorphic (1 × 2 mm. in section), and exhibit a patchy colouring and zoning in various light tints of purple and green. The borders are well defined by bright-green ægirine, which is strongly pleochroic from blue-green to yellow-green. The

[1] J. W. Gregory, Q.J.G.S., lvi, 1900, p. 223.
[2] Brögger, *Zeit. Krist.*, xvi, p. 30, 1890.
[3] Pl. XI, Fig. 3.

interior is chiefly titaniferous augite, with pleochroic tints of yellow-green, brown-purple, and violet, and a maximum extinction of about 40 degrees. Between this and the bordering ægirine there is every gradation of ægirine-augite. Numerous small crystals of a deep purple colour also occur, but they are never free from a ragged border of ægirine. The latter, however, exists alone in long wisps and leaf-like growths. Still smaller crystals and tiny drop-like granules of grey-green augite free from pleochroism are sprinkled over the groundmass. The granules of augite are frequently aggregated together in groups and linear series of varying sizes.

The *amphiboles* form a similar series of the barkevikite–arfvedsonite–hastingsite type. The larger crystals are perfectly idiomorphic and sometimes show conspicuous zoning and twinning. The pleochroic scheme is—

X near to a . . .	yellow-green	$Z > Y > X$
$Y = b$	reddish-brown	
Z near to c . . .	purple-brown	

This agrees closely with the pleochroism of barkevikite from Barkevik[1] and Lugar.[2] The extinction angle $Z < c$ is about 10°, and the birefringence is nearly that of ordinary hornblende, offering in this respect a striking contrast to the other members of the amphibole series. Many of the crystals are bordered with blue-green arfvedsonite, some of which has a red or purple tint in one direction suggesting katoforite. Frequently titaniferous augite and barkevikite have grown together in parallel orientation, with numerous common inclusions of sphene and titanoferrite.

The smaller crystals are lozenge-shaped and possess a deeper colouring and a more intense pleochroism. Some of them are barkevikite, and others, unbordered, belong to arfvedsonite or katoforite. There are also small prisms of a green amphibole, which is identical in appearance and birefringence with the hastingsite of the nepheline syenite. The same mineral occurs in association with granular augite, forming an irregular border around the aggregates.

Sphene in good idiomorphic crystals is abundant, and is generally found clinging to or included in the pyroxenes and amphiboles. It is nearly colourless and therefore the pleochroism is barely perceptible.

Phenocrysts of *nepheline* are small though well formed, and are occasionally seen included in or penetrating the minerals already described. A very few clear spaces occupied by *analcime* may be seen, bordered by the coloured minerals.

These minerals, with small amounts of *ilmenite* and *apatite*, are embedded in a clear transparent groundmass. The absence of felspar in the latter was proved by staining. Radiating needles of nepheline and cancrinite can be readily distinguished, and between them is an isotropic base, which, like the crystals of analcime already mentioned, has a refractive index of about 1·49, and is almost certainly to be referred to that mineral. Further evidence in favour of this diagnosis is provided by the high content of combined water present in the rock.

[1] Brögger, *Zeit. Kryst.*, xvi, p. 412, 1890.
[2] Scott, *Min. Mag.*, xvii, p. 139, 1914.

The nature of the groundmass and the absence of felspar, in conjunction with the melanocratic habit of the rock, suggest that it should be placed among the *monchiquites*. It differs, however, from most monchiquites in having a somewhat lower proportion of the mafic minerals, and more vitally in the total absence of olivine. The naming of this rock raises the important question whether the presence or absence of olivine in a rock should affect its name and classificatory position. The division of igneous rocks on a silica saturation basis, as recently developed by Professor Shand,[1] seems to afford a sound basis for a more satisfactory mineralogical classification than has yet been proposed. In it rocks containing quartz, felspathoids, or olivine, would be sharply and naturally distinguished from any in which those critical minerals were not present. This distinction is already frequently made. Thus we have basalt and olivine basalt, tephrite and basanite, nephelinite and nepheline basalt (a better name for which would be olivine-nephelinite). The natural distinction based on the principle of saturation,[2] and actual precedent are therefore both against any extension of the existing term monchiquite to include rocks free from olivine. The difficulty may be evaded by defining monchiquite so that olivine shall not be an essential mineral, leaving the term olivine monchiquite for the original monchiquite of Hunter and Rosenbusch.[3] The only alternative appears to be that of proposing a new name. The term *Fourchite*,[4] which is already available, cannot be applied to the Angola rock, since it was given to a rock which contains 75 per cent of titaniferous augite and is conspicuously poor in alkalies. The multiplication of new names within a group like that of the monchiquites is greatly to be deprecated, and since there are already some other monchiquites which contain no olivine, and yet which are certainly not fourchites, it would be an innovation of considerable advantage to adopt the first suggestion and speak of monchiquites and of olivine monchiquites. Not only would precision be gained, but petrologists, already overburdened with varietal names, would be saved the influx of fresh ones as geological exploration continues. The principle is one which has been applied to many other groups of rocks, and which could be still further extended.

It is proposed, then, to classify monchiquitic rocks on a mineralogical basis as follows, the term monchiquite alone implying the presence of phenocrysts of pyroxene and amphibole in approximately equal proportions.

[1] Geol. Mag., 1913, p. 508; 1914, p. 485. See also Scott, Geol. Mag., 1914, p. 319; 1915, p. 160.

[2] The American Quantitative Classification fails to observe this principle, and the result is somewhat unfortunate, particularly in Order 5 (Q/F or L/F $< 1/7$) which includes rocks that may contain felspars, or felspars with quartz, or felspars with felspathoids.

[3] "Ueber Monchiquit, etc.": Tscherm. Min. Pet. Mit., xi, p. 445, 1890. See also Evans, Q.J.G.S., lvii, p. 38, 1901. Rosenbusch did not consider olivine to be an essential constituent (*Elemente der Gesteinslehre*, 1898, p. 233).

[4] Williams, Arkansas Geol. Surv. Ann. Rep., vol. ii, p. 107, 1890.

Olivine-free.	*Olivine-bearing.*
Nepheline monchiquite.	Nepheline olivine monchiquite.
Leucite monchiquite.	Leucite olivine monchiquite.
Biotite monchiquite (including ouchitite).	Biotite olivine monchiquite (including alnoïte).
Monchiquite.	Olivine monchiquite.
Pyroxene monchiquite (including fourchite).	Pyroxene olivine monchiquite.
Amphibole monchiquite.	Amphibole olivine monchiquite.

According to this nomenclature the rock under discussion would be called a *nepheline monchiquite.*

Chemical characters.—A chemical analysis of the work and a calculation of the norm gave the following results:—

Analysis.		*Molecular Proportions.*	*Norm.*		
SiO_2	46·06	·767	Orthoclase	17·79	Salic = 64·89
Al_2O_3	17·04	·167	Albite	19·39	
Fe_2O_3	4·01	·025	Anorthite	5·56	
FeO	4·51	·063	Nepheline	22·15	
MgO	3·15	·079	Diopside	16·85	Femic = 31·98
CaO	7·43	·132	Hypersthene	0·10	
Na_2O	7·13	·115	Magnetite	5·57	
K_2O	2·98	·032	Hæmatite	0·16	
H_2O +	3·32	—	Ilmenite	5·93	
H_2O −	0·70	—	Apatite	0·67	
CO_2	1·18	·027	Calcite	2·70	
TiO_2	3·15	·039	H_2O =	4·02	
P_2O_5	0·23	·002			
	100·89		Total	100·89	
Sp.gr.	2·76				

In the quantitative classification the analysis falls into the following divisions:—

Group II	Dosalane.
Order 6	Norgare.
Rang 2	Essexase.
Subrang 4	Essexose.

It is significant that most olivine monchiquites have the magmatic symbol III, 6, 2, 4 (analyses IV and V in the table below), and the nepheline monchiquite of Angola falls into Group II, as might be anticipated, on account of its lower proportion of femic to salic constituents. This difference is at once evident in thin section, and is also indicated chemically by the comparatively high percentages of alkalies and alumina and the low percentages of iron and magnesium. The analyses cited below also bring out the relation of the rock to the tinguaites (I) and the augitites (VI). The magmatic symbols clearly show that it lies midway between these somewhat extreme types. The olivine monchiquite of Cabo Frio, Brazil (V) is that which agrees most closely in chemical composition with the Angola variety, and the differences, especially between the contents of magnesium, iron, and aluminium oxides, are of the kind to be expected in comparing an olivine-bearing rock with one which is free from that mineral.

	I.	II.	III.	IV.	V.	VI.
SiO_2	55·02	53·28	46·06	45·17	46·48	42·25
Al_2O_3	20·42	16·38	17·04	14·78	16·16	16·26
Fe_2O_3	3·06	6·11	4·01	5·10	6·17	8·43
FeO	1·82	4·52	4·51	5·05	6·09	5·46
MgO	0·59	2·50	3·15	6·26	4·02	5·49
CaO	1·67	3·09	7·43	11·06	7·35	9·75
Na_2O	8·63	6·42	7·13	3·69	5·85	4·45
K_2O	5·38	4·18	2·98	2·73	3·08	1·92
H_2O+	2·77	3·52	3·32	3·40	4·27	2·43
H_2O-			0·70			
CO_2	—	—	1·18	—	0·45	—
TiO_2	—	—	3·15	—	0·99	2·52
P_2O_5	0·06	0·15	0·23	0·51	—	1·04
MnO	0·22	—	—	0·35	—	—
Totals	100·00	100·15	100·89	100·00	100·91	100·00
Magmatic Symbols	(I) II,6,1,4	II, 6, 1, 4	II, 6, 2, 4	III,6,2,4	III,6,2,4	III,6,3,4
and Names	Laurdalose.		Essexose.	Monchiquose.		Limburgose.

I. Average of fifteen analyses of *Tinguaite* after Daly, *Igneous Rocks*, 1914, p. 35.

II. *Ulrichite* (Camptonitic tinguaite). Dunedin, New Zealand. P. Marshall, Q.J.G.S., lxii, p. 397, 1906.

III. *Nepheline monchiquite*. 20 kilometres north-east of Senza do Itombe, Angola. Arthur Holmes, analyst.

IV. Average of sixteen analyses of *Olivine monchiquite*, after Daly, *Igneous Rocks*, 1914, p. 36.

V. *Olivine monchiquite*. Cabo Frio, Brazil. Hunter and Rosenbusch, *Min. pet. Mitth.*, xi, p. 445, 1890. M. Hunter, analyst.

VI. Average of six analyses of *Augitite*, after Daly, *Igneous Rocks*, 1914, p. 30.

(*To be concluded in our next number.*)

NOTICES OF MEMOIRS.

A Discussion upon the Age of the Lower Tertiary Marine Rocks of Australia.[1]

By R. Bullen Newton, F.G.S.

THE author referred briefly to the valuable palæontological work on the Australian Tertiaries carried out by such prominent authors as M'Coy, Ralph Tate, Dennant, Hall, Pritchard, etc., the majority of whom favoured an Eocene age for the Lower Tertiary deposits of Australia. The late G. F. Harris doubted the existence of such a formation, whilst M. Cossmann could see no relationships among the Lower Tertiary Opisthobranchs from Australia with Eocene forms from Europe.

Mr. F. Chapman, Palæontologist of the Melbourne Museum, has studied this subject, and proves very conclusively that those beds hitherto regarded as Eocene belong to the Miocene period—a view

[1] From Reports of the Eighty-fourth Meeting British Association for the Advancement of Science, Australia, 1914, published 1915, p. 375.

which the author fully supports. Mr. Chapman's work on the Batesford Limestone is important in this connexion, because of its containing *Lepidocyclina*, *Amphistegina*, and *Lithothamnium*—all of which characterize the Miocene beds of Europe, Java, Sumatra, Borneo, Formosa, etc.; the absence of nummulites in this limestone is against its age being either Eocene or Oligocene. These same limestones have also yielded Mollusca and Brachiopoda, as well as *Carcharodon megalodon*, which has its origin in Miocene rocks. The author was of opinion that the Lower Tertiary faunas of Australia presented in some cases a recent facies, in others a Miocene facies, with relationships to both European and South American species of that period. Among shells showing a resemblance to those of present-day seas, he mentioned *Cassis contusus*, *Siphonalia spatiosa*, *Typhis laciniatus*, all Tate's species, and mostly from the Muddy Creek deposits; and many more species might be quoted exhibiting a more or less recent appearance. Among fossil forms more particularly referred to was the *Aturia aturi*, var. *australis*, which has been recognized as coming from the Eocene of Australia. Although given a varietal name, this Cephalopod is not to be separated from the Miocene species of Europe known as *Aturia aturi*, and with this statement Mr. Crick, of the British Museum, thoroughly agrees. The species is found in many of the Australian deposits, as also in the Table Cape Beds of Tasmania, the Oamaru Beds of New Zealand, the Navidad Beds of Chili, South America, as also in the European Miocene. The more or less pointed rostrum of *Spirulirostra curta* illustrates an affinity with Miocene forms rather than with Eocene, which are more obtuse.

The large *Cypræas* described by M'Coy as Oligocene should more probably be regarded as Miocene, since they come from the Gellibrand River Beds, Muddy Creek deposits, etc., which also contain the *Aturia aturi* before mentioned. The Brachiopods of the Lower Tertiary deposits of Australia show a somewhat recent facies, a striking form being *Magellania garibaldiana*—a species occurring in the Mount Gambier Beds in association with the *Aturia aturi*.

Even before Mr. Chapman pointed out the Miocene characters of the Lower Tertiary deposits of Australia, Dr. Ortmann, of the United States, had published in 1902 his important monograph on *The Tertiary Deposits of Patagonia*, in which he compared the faunas of that continent with those of Australia. His researches were against the presence of Eocene in the Tertiaries of Australasia, and those beds hitherto recorded as such he identified as Miocene, and contemporaneous with the Pareora Beds of New Zealand, Navidad Series of Chili, and the Patagonian deposits, all of which showed unmistakable affinities with each other and favoured the view that a former connexion existed between South America and Australasia.

The term Oligocene among Australasian marine Tertiaries, the author was inclined to abandon because of the absence of *Nummulites*, their place being taken by *Amphistegina* and Lepidocycline forms of Foraminifera. Such rocks he would regard as Miocene. This would apply to the Balcombian and Janjukian Beds of Mornington, etc., and the older deposits of Muddy Creek and other localities.

REVIEWS.

I.—Geological Survey of Scotland.

The Geology of the Country round Beauly and Inverness. By J. Horne, LL.D., F.R.S., and L. W. Hinxman, B.A., F.R.S.E.; with contributions by B. N. Peach, LL.D., F.R.S., and E. H. Cunningham Craig, B.A. Memoirs of the Geological Survey, Scotland. Explanation of Sheet 83. H.M. Stationery Office, 1914. Price 2*s*.

THIS memoir has been issued in advance of the corresponding colour-printed map, the printing of which is delayed owing to pressure of work at the Ordnance Survey Office, occasioned by the European War. It is descriptive of the district from Inverness north to Strathpeffer, including Beauly and a part of the Black Isle, extending almost to Munlochy. Two main types of rock occur in this country: the Highland schists and metamorphic rocks form most of the western half of the Sheet, while the conglomerates and sandstones of the Orcadian or Middle Old Red Sandstone underlie the agricultural and more densely populated country near the coast.

The metamorphic rocks of the interior mountainous tract are not essentially different from those that occur in the Sheet to the west (82), of which a description was published in 1913. The Moine Gneisses of this part of Scotland are an old sedimentary group now represented by mica schists and quartzose biotite-granulites. With little variation they extend over wide areas; graphite schists and limestones are comparatively rare in this series, but at Rebeg, about 8 miles west-south-west of Inverness, a limestone occurs which is ascribed by Dr. Horne to the Moine rocks.

Another group of metamorphic rocks more varied in composition and character, as it included many types of orthogneiss and paragneiss, is represented by small outcrops in Glen Orrin, Glen Urquhart, and at Loch Luichart. These have attracted some attention, as among them occur kyanite-gneiss and white marble, unusual types of rock in eastern Inverness-shire. Glen Urquhart is known to mineralogists as a locality for interesting minerals. In the memoir they are assigned to the Lewisian Gneiss, but the evidence on which this conclusion is founded is not stated, as it was obtained actually in the district further west and has been given in the Memoirs on Glenelg and Central Ross. The Moine Gneisses are believed to rest unconformably on an irregular, highly eroded surface of the Lewisian Gneiss, but the interpretation of the junctions is rendered very obscure owing to complicated folding and metamorphism.

The Old Red Sandstone of the eastern part of the Sheet is very thick and at the same time very poor in organic remains. Dr. Peach estimates that on the north side of the Black Isle syncline there are 7,000 feet of conglomerates, sandstones, and shales. Two fish-beds with limestone nodules, like those found at Cromarty by Hugh Miller, occur in the Killen Burn, about 3 miles west of Avoch, and have yielded the Orcadian fishes *Coccosteus decipiens*, Ag., *Osteolepis macrolepidotus*, Ag., and *Gyroptychius microlepidotus*, Ag.,

with some plant-remains. A useful feature of the memoir is the account of the geology of the Strathpeffer district and the relation between the mineral waters and the fetid limestones and bituminous shales of the Old Red Sandstone of that locality. This was pointed out long ago by Hugh Miller, but his interesting speculations on the connexion between mineral waters and fossil fishes are not mentioned in the memoir.

One of the great structural lines of Scotland, the Great Glen fault, passes along the line of the Caledonian Canal, a little north of Inverness. Dr. Horne estimates that it has a downthrow to the south-east amounting to at least 6,000 feet, from its effects on the Middle Old Red Sandstone. Movement along this fault gave rise to the Inverness earthquake of 1901, of which Dr. Davison has remarked the similarity in character with the Japanese earthquake of 1891, indicating that mountain-building processes are not yet ended in the Scottish Highlands.

The glacial geology of the district presents no features of special interest, but the raised beaches of the Moray and Cromarty Firths are well known to geologists and geographers. Many passengers on the Highland Railway are familiar with the raised beaches of Kessock, which are illustrated in the memoir by a photographic plate. Visitors to Inverness must also be familiar with the conical gravel hill, known as Tomnahurich, that stands in the Ness Valley to the west of the town. It rises to a height of 200 feet, and was considered by Helland to be a moraine, but is regarded as of fluvio-glacial origin by the authors of the memoir.

II.—The Problem of Volcanism. By G. P. Iddings, Ph.B., Sc.D. pp. 273, with 86 figures, mostly photographic plates, Oro-Bathygraphical Chart of the World, coloured folding plate showing Recent and Tertiary volcanoes. Yale University Press; Oxford University Press; 1914. Price £1 1*s.* net.

THE treatment of the subject is frankly speculative. Once volcanic phenomena have been introduced by the citation of familiar examples, the question of the source of volcanic temperatures is raised. To meet this an account is given of nebular hypotheses, illustrated by fifteen beautiful photographs of nebulæ, fourteen of them from the Lick Observatory. The older hypotheses of Buffon, Kant, and Laplace are passed in review, and then a very sympathetic rendering is accorded to the contributions for which we are indebted to Chamberlin working, as that author tells us, in collaboration with Moulton. Chamberlin's contention is that the solar system has evolved from a spiral nebula, which in its turn may have originated in a tidal explosion of the sun during the near approach of some other star. It must be remembered that Laplace was writing in the dark when he pictured his great nebula. Nowadays improved telescopes coupled with photography enable us to discern such objects in ever increasing numbers. Among them spiral nebulæ, emitting a continuous

spectrum, greatly preponderate, though variously shaped gaseous varieties are also found. Had Laplace been in possession of these facts, he, too, would probably have claimed a spiral ancestry for the solar system, and developed his mathematical treatment accordingly. It is not a little curious that Buffon should more nearly have anticipated Chamberlin's hypothesis, which latter, writes Iddings, "will be recognized as a refined expression of the conception of Buffon. The fundamental ideas are alike, the modern expression has had the advantage of a hundred and fifty years of astronomical discoveries and of improvements in the physical sciences." One of the features of the presentation of the hypothesis to-day is the claim that a spiral nebula can easily be conceived capable of meeting the dynamical requirements of a developing solar system in such matters as angular momentum, whereas a discoid gaseous nebula would find itself insolvent if faced with such liabilities.

According to Chamberlin the central mass of a spiral nebula represents a sun, and the cloudy knots distributed along the coiling arms are the nuclei of planets yet to be, while the nebulous material is the manna upon which these nuclei are to feed until they become perfected. Here, then, is the answer to the original question. The earth may have inherited a large hot nucleus, or on the other hand it may have grown from small beginnings by slow accretion in the cold. Iddings is of the opinion that the latter is the more likely alternative, and is insistent that we have no warrant to assume higher temperatures for the interior of the earth than those that are manifested at the surface through volcanic action, namely from 1,000° to 1,500° C. He supports this contention by pointing to the tidal rigidity of the earth, which he thinks suggestive of a restricted internal temperature. The heat of volcanic activity he attributes to condensation, radio-activity, and chemical re-arrangement; how much relatively should be assigned to each of these three factors he leaves to the future to decide. Joly's name is, of course, mentioned in connexion with radio-activity, but it is strange to read the partial truth that this investigator "considered it probable that radium exists throughout the earth"; it is not added that Joly is in essential agreement with Strutt in assuming a marked concentration in the more superficial portions. Further, is it a sufficient argument to say that "volcanic rocks do not contain any greater amount of radio-active matter than other rocks investigated, so that there cannot be any question of the possible local heating of igneous magmas by this means, as has been suggested by some geologists?" Surely in a uniformly radio-active crust, or even in one in which radio-activity fell off gradually downwards, one would confidently expect increasing temperature with increasing depth because of the relative thermal isolation at low levels. It is a simple conception that at a certain depth fusion supervenes, and that vulcanism is a complex convection phenomenon set in motion by radio-activity. But perhaps Iddings has safeguarded himself in this direction by the use of the word *local*.

Like Chamberlin, the author is a convinced adherent of the permanency of ocean-basins, and also of the principle of isostacy in its major applications. He takes an independent line in accounting

for the origin of the great oceans, for he thinks that they overlie relatively large and dense planetismals, which have been welded with the substance of the growing earth. These dense accretions he recognizes not only through the sagging of the earth's surface above them, and the influence they exert upon the plumb-line, but also more directly through the products of their volcanoes. He maintains that there are two great provinces of igneous rocks, the Oceanic and the Continental respectively. What may be termed the average igneous rock of the former has a density of about 3·00, and of the latter 2·85. The Atlantic and Pacific hordes of various authors he dismisses as "highly artificial misnomers".

A difficulty which must occur to anyone in considering the application of Iddings' hypothesis, even in America, is the continental distribution of the Columbia River Basalts. This point is dealt with in advance as an example of the danger of loose petrographical nomenclature. Iddings takes two analyses, representative of large masses in the so-called basalt series, and recognizes in both a decidedly andesitic flavour. The treatment of the matter is too condensed to be satisfactory, and one wonders why the predominantly basic magmas (according to general belief) of Iceland and the Hebrides, of the Deccan, and of the Zambezi region, to take well-known examples, are not referred to. The Zambezi lavas are of great geological antiquity, and once we step back to consider such ancient products another lion is met with on the path. How is it that Scotland in Old Red Sandstone times furnished a typical continental suite of igneous rocks, and in New Red Sandstone times an equally typical oceanic suite? One might be tempted to argue that in this case an ocean basin had not been permanent, were it not that the lavas of New Red Sandstone age were erupted on a desert and many of their cracks and vesicles contemporaneously choked with millet-seed sand.

As might be expected from the foregoing, Iddings does not follow Daly in his speculations. For Iddings, the igneous rocks of a district afford a sample of the deeply buried foundation stones. During its upward progress the magma is frequently separated into more or less dissimilar fractions by differentiation, but is practically never polluted by assimilation.

In a short review it is impossible to follow our author further. A reader who enjoys a plunge into a sea of doubt is recommended to dip into the pages of this book. He is sure to be stimulated for a time, but, if in stature like the present writer, he will find it wearisome before long to be so continually beyond his depth.

One last point may be noticed. In the construction of a book of comprehensive aim it goes without saying that all available sources of information have not been consulted. Still, it is surprising to find that Heim's later writings have made so little impression that a 'double fold' is reproduced from the *Mechanismus* to illustrate Alpine structure.

E. B. Bailey.

REPORTS AND PROCEEDINGS.

I.—Geological Society of London.

1. *June* 9, 1915.—Dr. A. Smith Woodward, F.R.S., President, in the Chair.

The following communications were read:—

1. "The Accessory Minerals of the Granitic Rocks of the English Lake District." By R. H. Rastall, M.A., F.G.S., and W. H. Wilcockson, B.A.

The work described in this paper arose out of independent researches on the mineral composition of sediments, in which it became desirable to study the genesis of certain minerals. Preliminary investigations promised results of interest if the rocks of a whole district were examined, and for this purpose the Lake District was selected. The rocks here described are the granites of Skiddaw, Shap, and Eskdale, the microgranite of Threlkeld, and the granophyre of Buttermere and Ennerdale.

The material was pounded in a mortar, washed and panned, and the concentrate separated in bromoform after the removal of the magnetic portion.

The general results showed a well-marked variation of accessory minerals between the different intrusions, but a similarity between parts of the same intrusion, although the minerals of apophyses are not always the same as those of the main mass. No evidence is afforded for a genetic connexion between the different intrusions.

One of the most remarkable results obtained is the rarity of magnetite and the wide prevalence of pyrrhotite which was present in every sample examined, some thirty in number. Special attention was paid to the characteristics of the zircon crystals, which lent no support to the conclusions of Chrustchoff as to the occurrence of definite types in granite and gneissose rocks respectively. In parts of both the Skiddaw granite and the Threlkeld microgranite, anatase and brookite were found in abundance. It was not possible to determine their origin. Epidote is the characteristic mineral of the Ennerdale granophyre, while garnet is abundant at Threlkeld and Eskdale. The Eskdale granite also contains much tourmaline. The Shap granite is especially characterized by apatite and sphene.

It is concluded that descriptions of accessory minerals founded only on examination of rock-slices are inadequate and misleading; it is only by concentration that the rarer constituents can be satisfactorily determined.

2. "The Rocks of the Lyd Valley, above Lydford (Dartmoor)." By Frederic Philip Mennell, F.G.S.

The paper deals chiefly with a small area on the north-east of Dartmoor, though some of the conclusions are applicable to nearly all that part of the moor which lies north of the portion recently mapped by the Geological Survey. In the immediate neighbourhood of Lydford the progressive alteration of the Carboniferous rocks within the metamorphic aureole surrounding the granite is described in detail, and it is shown that they are consistently cordierite- and biotite-bearing, like those examined by Mr. Barrow at Holne. North

of the altered limestone or 'calc-flinta' of Down-town, however, the type of alteration is entirely different, and leads to the inference that the beds are quite distinct. The change is of much more than local significance, as from this point all round the north of the moor, at least as far as South Zeal, there is no bed of any thickness containing cordierite, while chiastolite, white mica, and andalusite proper are characteristic. Coarse andalusite rock and altered shale, with remarkable skeleton crystals of chiastolite, are described from the Nodden quarries, together with other types of hornfels. It is clear that the beds occupying the northern part of the contact-zone belong to a definite series. There is strong evidence that the cover of the granite mass has a dome-like character, and that precisely the same stratigraphical horizon is in immediate contact with the granite all the way from Sourton to Drewsteignton.

The granite of Brator, not far from the best exposures of coarse cordierite-hornfels, is described. It is a biotite-bearing rock containing a little microcline, as well as orthoclase and oligoclase. It is rich in cordierite, recrystallized from sedimentary material absorbed into the magma. Several offshoots from the granite have been noted at various points along the Lyd. One near Nodden Gate is of interest, as containing topaz in remarkable abundance.

II.—Zoological Society of London.

1. *April* 13, 1915.—E. T. Newton, Esq., F.R.S., in the Chair.

Dr. A. Smith Woodward, F.R.S., F.Z.S., exhibited an anterior horn of a woolly rhinoceros (*Rhinoceros antiquitatis*), obtained for the British Museum, from frozen earth in Northern Siberia, by Mr. Bassett Digby. The horn must have measured originally nearly a metre along the curve of the anterior border. It has been cut and trimmed in places by the finders, but is sufficiently well preserved to show its laterally compressed shape and sharp posterior border.

Dr. Robert Broom, D.Sc., C.M.Z.S., read a paper on some new Carnivorous Therapsids in the Collection of the British Museum. Most of the specimens described have been for many years in the collection, but owing to their small size and imperfect condition they have not hitherto been recognized as new. Five species, belonging to four new genera, are Therocephalians. Two species, one of which belongs to a new genus, are Gorgonopsians, and one is a new species of a previously known Cynodont genus.

2. *May* 11, 1915.—Dr. A. Smith Woodward, F.R.S., V.P., in the Chair.

Dr. R. Broom, M.D., C.M.Z.S., read a paper on the Anomodont genera, *Pristerodon* and *Tropidostoma*.

Pristerodon, described by Huxley in 1868, is a very near ally of *Dicynodon*, differing mainly in having a series of molars which are smooth in front and have a series of denticulations behind. The males are tusked, the females without tusks. *Oudenodon raniceps* of Owen is a species of *Pristerodon*; while *Opisthoctenodon agilis*, Broom, and probably also *Opisthoctenodon brachyops*, Broom, are other species of *Pristerodon*.

In 1889 Seeley described two occiputs under the name *Dicynodon*

microtrema and *Dicynodon* (*Tropidostoma*) *dunni*. As pointed out by Lydekker, these belong to the one species, *D. microtrema*.

CORRESPONDENCE.

ANDALUSITE AND CHIASTOLITE.

Sir,—I have read with much interest the note on the genesis of chiastolite in the May Number of the Geological Magazine.[1] Since I have had some considerable experience in the examination of rocks containing this mineral, may I be permitted to offer a few remarks on the subject? As is well known, chiastolite slate forms a conspicuous feature of the metamorphic aureole of the Skiddaw granite, especially in its outermost zones, while andalusite is likewise a common constituent of the more highly altered rocks nearer to the outcrop of the granite.

The author of the paper above alluded to states that inclusions of carbonaceous matter are essentially absent from andalusite: with this conclusion I cannot agree. My experience shows that the structures commonly described as chiastolite are, at any rate in the Skiddaw rocks, shimmer aggregates or pseudomorphs of colourless micaceous and chloritic minerals having the external form of crystals of andalusite and undoubtedly derived from them. This accounts for the inferior hardness and density of chiastolite alluded to by the author of the paper mentioned. In certain bands of the Skiddaw Slate Series there are numerous large and well-developed crystals of transparent and perfectly fresh andalusite, possessing all the characteristic optical properties of this mineral, with very conspicuous regularly arranged black inclusions: such crystals often show clearly the rose-pink pleochroism of andalusite, exactly as in the granitic rocks in which this mineral likewise occurs.

I venture to submit, therefore, that more evidence is required for the establishment of a real mineralogical distinction between these two forms, hitherto regarded as varieties of the same species.

R. H. Rastall.

Sedgwick Museum, Cambridge.

MISCELLANEOUS.

Erratum.—In the obituary notice of the late Mr. F. W. Millett some words have been unfortunately transposed, on p. 288 of our June Number; the first three lines should read: "Mr. F. W. Millett was chiefly known to geologists for his publications on the Foraminifera of the St. Erth Clays, and as an active worker on the more recent forms."

Addenda.—Please add the following magnifications to the illustrations in Mr. P. G. H. Boswell's paper on "The Petrology of the Suffolk Box-stones (Crag)" (June Number, pp. 250–9): Plate X, Fig. 1, × 26 diam.; Figs. 2–4, × 20 diam.; Text-fig. 1, p. 251, and Fig. 2, p. 252, × 20 diam.; Text-fig. 3*a*, p. 256, × 12 diam., and 3*b*, p. 256, × 25 diam.

[1] Geol. Mag., May, 1915, p. 224.